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DEPARTMENT OF THE INTERIOR
ALBERT B. FALL, SECRETARY
BUREAU OF MINES
H. FOSTER BAIN, DIRECTOR

[redacted]

TREATMENT OF THE TUNGSTEN ORES OF BOULDER COUNTY, COLO.

BY

J. P. BONARDI and J. C. WILLIAMS

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This Report is the Result of Work Done Under Cooperative Agreement
With the Colorado School of Mines

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TREATMENT OF THE TUNGSTEN ORES OF BOULDER COUNTY, COLO.

By J. P. Bonardi and J. C. Williams.

INTRODUCTION.

Until the end of 1918 Boulder County ranked as one of the foremost tungsten-producing districts of the world, but in August, 1919, there was practically no production in the district. The operators there could not compete with tungsten ores from foreign sources, particularly China, Burma, and South America. As a result there has been a strong movement for placing a protective tariff on all imported tungsten ores and products; and it seems to be the general belief of tungsten producers that some form of protection is necessary to the maintenance of the industry in this country.

The stimulus, due to the great demand for tungsten alloys in the manufacture of munitions during the war, was felt in all the productive localities of the world. The ores of Boulder County were especially in demand on account of their comparative freedom from harmful impurities, and this demand greatly extended mining operations in the district and increased the efficiency of the general milling practice there.

SCOPE OF REPORT.

This paper deals largely with the development of milling practice in Boulder County, the ore-dressing methods in use, and the local manufacture of ferrotungsten and tungstic oxide. The geology of the district and the mining methods are treated only briefly. Local methods of analyzing ores, concentrates, ferrotungsten, and tungsten metal powder are discussed.

Figures giving the production of tungsten concentrates in the Boulder district, in the United States, and in the world, data on the buying of tungsten ores, costs of production, and the normal tungsten requirements in this country are presented. Imports and exports of tungsten ores of the United States are mentioned briefly.

The writers hope that this report will prove of interest to all those interested in the treatment of tungsten ores and the manufacture of tungsten acid, tungsten powder, and ferrotungsten.

ACKNOWLEDGMENTS.

The writers are greatly indebted for the many courtesies shown by those connected with the tungsten mining companies in the Boulder district, among whom are W. F. Bleecker, Louis C. Schultz, W. Y. Bleakley, F. J. Gibson, A. J. Guerber, William E. Ellis, W. E. Crosley, and Roy B. Edson, of the Tungsten Products Co.; William Loach and W. G. Roseborough, of the Wolf Tongue Mining Co.; Thomas McGrath, of the Mojave mill; George Teal and Clifton A. Barr, of the Red Sign Mining Co.; J. A. McKenna, Fred Barnett, and J. W. Conklin, of the Vasco Mining Co.; Nelson Franklin and S. B. Tyler, of the Rare Metals Ore Co.; and J. B. Ekeley, of the Black Metals Reduction Co.

Acknowledgment is also due to J. G. Hibbs, F. C. Armstrong, Hugh F. Watts, W. R. Lewis, and J. G. Clark, of Boulder, for valuable information and helpful suggestions; as well as to R. B. Moore, now chief chemist of the United States Bureau of Mines, and Dr. V. C. Alderson and Robert M. Keeney, of the Colorado School of Mines.

GEOGRAPHICAL DISTRIBUTION OF ORE.

EXTENT OF DISTRICT.

Boulder County is one of the smallest counties in Colorado. It is rectangular in shape, measuring 32 miles east and west by 24 miles north and south. Its southeast corner is about 12 miles north of Denver.

As the accompanying map (fig. 1) shows, the tungsten district of Boulder County is small and rather well defined, having a length of about 12 miles in a northeast and southwest direction and a width of about 7 miles. This area includes nearly all of the scattered deposits lying outside of an area of about 10 square miles in which are found the richest and largest deposits. There are a few deposits near by in the north end of Gilpin County, near Rollinsville.

As the productive area is small and the field has been thoroughly prospected under the stimulus afforded by the high prices of 1914–15, the chances of finding new deposits are slight.

The more important towns of the district are Nederland, the chief business center; Lakewood and Stevens Camp, the principal active mining centers; Cardinal, Sugar Loaf, Magnolia, and Rollinsville. The altitude of Nederland is 8,237 feet.

The district is reached by the Denver, Boulder & Western Railroad and by the Denver & Salt Lake Railroad (Moffat Road). Sugar Loaf and Cardinal are on the Denver, Boulder & Western; Rollinsville is on the Moffat Road. Cardinal is about 2 miles north of

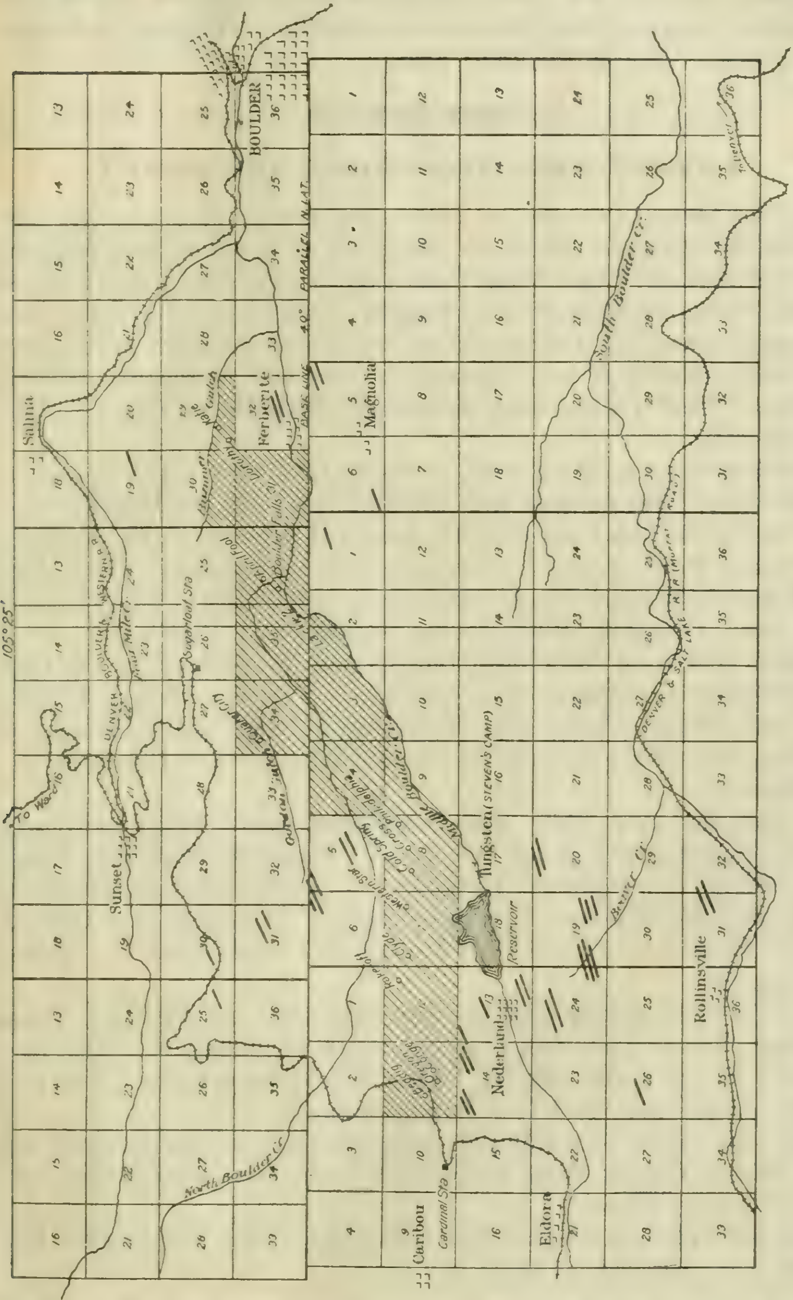


FIGURE 1.—The tungsten district of Boulder County, Colo. The tungsten district is shaded; mines outside this district are indicated by heavy diagonal lines.

Nederland, and Rollinsville is 4 miles south. Motor stage lines run from Boulder to the various towns of the district. An excellent highway, suitable for heavy motor truck hauling, runs up Middle Boulder Canyon from Boulder to Nederland, 17 miles, following the course of Middle Boulder Creek.

TUNGSTEN MILLS.

PRINCIPAL PRODUCING MINES OF THE DISTRICT.

At the time of the authors' visit to the district, January, 1919, the plants in operation, which are described in detail in this bulletin, were as follows: Black Metal Reduction Co., Boulder, tungstic oxide plant; Tungsten Products Co., Boulder, concentrator, ferroalloy and tungstic oxide plant; Grimm concentrating mill, Boulder Canyon, near Ferberite; Red Sign mill, Ferberite; Vasco mill, Tungsten (Stevens Camp); Wolf Tongue mill, Nederland; Rare Metals Ore Co. mill, Rollinsville.

Several other tungsten mills in the district were not in operation at the time. Among these were the following: Mojave-Boulder Mining Co., in Boulder Canyon, at the mouth of Bummer Gulch; Boulder Tungsten Production Co., Tungsten (Stevens Camp); Clarasdorf mill, Middle Boulder Creek; Black Swan mill, Salina; Primos Chemical plant, Copeland; Black Prince tungsten mill, Ferberite.

Mills that were not visited, though still in operation at the time the district was visited, were as follows: Tungsten Mining & Milling Co., Beaver Creek, near Rollinsville; Long Chance Mining & Milling Co., Beaver Creek, near Rollinsville; Primos Chemical Co., Lakewood.

Companies other than those mentioned above which have produced tungsten ores in the district are: Tungsten Mines Co., Tungsten Metals Co., Colorado Tungsten Co., Tungsten Mountain Mines Co., Duncan Mining Co., Commonwealth Tungsten Co., Gold & Silver Mining Co., April Fool Mining Co., Eagle Rock Co., Victor Mining Co.

In the Cold Spring district, near Lakewood, are the Cross mine, Orange Blossom, and Cold Spring, which are among the chief producers of the entire district. Near Nederland are the Clyde and other groups that have been large producers.

The ore treated by the Primos Chemical Co. is chiefly derived from the famous Conger mine, the Beddig, Lone Tree, Cork Screw, and Nos. 18 and 4 mines.

At Ferberite are the Red Sign mines which have supplied the Red Sign mill previously mentioned.

At Beaver Creek, near Rollinsville, are the following mines, which were large producers during 1918: Elsie, Long Chance, Mammoth, Manchester, Ebony, Fitzsimmons.

At Tungsten, Stevens Camp, are the 13 mines (numbered 1 to 13) of the Vasco Milling & Mining Co.

HISTORY OF TUNGSTEN MINING IN BOULDER COUNTY.

DEVELOPMENT PRIOR TO 1915.

The history of the tungsten industry in Boulder County illustrates well how a valuable mineral may be overlooked because of ignorance of its nature or because of its being of no economic value at the time of its discovery, and yet become of importance later when conditions change. In 1870 Sam P. Conger discovered the famous Caribou silver mine at Caribou, and a few months later the Boulder County mine, and Caribou was erroneously heralded as the richest silver district in Colorado and one of the largest in the world. The miners and prospectors who flocked into the district soon became familiar with a heavy dark mineral, found as "float," to which they gave various names, such as "heavy iron," "black iron," "hematite," and "barren silver." In the early part of the year 1900, Conger's partner, W. H. Wanamaker, who had seen the tungsten ores found in the Dragoon Mountains of Arizona, recognized this "float" as an ore of tungsten. Conger and Wanamaker kept their discovery a secret and in August, 1900, obtained a lease on the Boulder County ranch for the purpose of working the tungsten placers and developing veins. By the end of the year about 40 tons of high-grade ore had been taken out, which was purchased by the State Ore Sampling Co. of Denver. Half of it netted about $1.60 a unit. The other half was sold to Morris Jones, representing the Great Western Exploration & Reduction Co., at $60 per ton, or about $1 per unit. T. S. Waltemeyer, who was associated with Conger and Wanamaker, concentrated the ore.

In 1901 the reported production was 65 tons of concentrates having a tungstic acid content of 65 per cent. This was sold at about $2.25 a unit. In 1902 the market was extremely dull and much difficulty was experienced in selling the concentrates, but considerable prospecting and some development were done. The year 1903 was very favorable for tungsten producers, and in the Boulder County field there was considerable development. From 1903 until nearly the end of 1907 production was reasonably steady, but the financial depression late in 1907 arrested progress. The production in 1908 was about half of that in 1907; that of 1909 was only slightly below that of 1907; and the production in 1910 exceeded that of 1907.

Until the end of 1914 there was no development of particular importance.

DEVELOPMENT SINCE 1915.

By the middle of 1915 the demand for high-speed tool steel, of which tungsten is usually a component, became so great as to cause feverish activity among the owners of the known Boulder County deposits. Between January and June, 1916, there were 10 mills treating ferberite ores and six of these mills were new. By the end of June five old mills were being overhauled to supply some of the demand for milling capacity and three new ones were under construction.

In the tungsten mining camps the high prices brought about a boom similar to the booms caused by important gold discoveries. Nederland, which had been a little village of a few dozen homes, became almost overnight a bustling town of 3,000 or more inhabitants. Optimism prevailed throughout the entire district, and fabulous prices were asked for properties that showed nothing more than a streak of tungsten ore in the bottom of a 10-foot discovery shaft. Leases on old mine dumps and mill-tailing ponds were sought eagerly.

The price of tungsten rose to unheard-of heights, $75 a unit or more being the quotation for nearly two months, and at least one lot is known to have been sold for $105 a unit. Such high prices caused the large users to import tungsten ores from South America and later China, as these foreign ores could be laid down in this country very cheaply. As a result of these importations the market broke rapidly, and during the latter part of 1916, 1917, and nearly all of 1918 was fairly steady at about $25 a unit. The small demand, upon the signing of the armistice, together with the large importations and stocks held by dealers, forced the price down so much that early in 1919 all of the Boulder County producers were forced to suspend operations.

MINING AND MILLING.

MINING METHODS.

In general the ore bodies of the district are lenses a few feet long, but a few ore bodies have reached the exceptional length of 150 to 200 feet. These extend at right angles to the strike of the vein; they may reach a width of 14 feet. The veins range in thickness from a fraction of an inch to several inches. Most of the shafts are comparatively shallow—between 200 and 300 feet—although one, the Conger, is more than 1,000 feet deep. Generally the veins dip steeply and only rarely dip as low as 45°.

In development the usual practice is to crosscut from a vertical shaft until a vein is reached and then to follow it until it opens out. Then the vein is stoped by shrinkage stoping, the muck line being kept at a suitable distance from the back by drawing the excess ore through chutes into cars in the levels. If a high-grade streak is discovered, it is carefully broken out and kept separate from the lower-grade ore; usually a certain amount of hand sorting is done in the stopes. As a rule very little timbering is required.

A large amount of placer mining has been done, as the peculiar nature of the veins and of the ferberite is conducive to the formation of placer tungsten. Surface mining has been carried on extensively by open cuts, trenches, and shallow shafts. A large amount of rich ore has been recovered simply by picking up pieces of high-grade float and by using small jigs operated by hand or by a gasoline engine.

Expensive pumping equipment is not necessary, as the veins are comparatively dry.

Many of the mines are away from the creeks where most of the mills are situated, and the ore from these mines must be hauled by wagons or teams or, from the more easily accessible properties, by motor trucks.

MILLING METHODS.

As there are many small mines sending different kinds of ore to the mills of the large companies, the nature of the mill feed varies widely. The difficulties encountered in treating small lots of ores having different physical characteristics are thoroughly realized by all mill men. A mill well equipped for treating ores in which the ferberite occurs coarsely crystalline may not efficiently treat the "hornstone" ores, which require extremely fine grinding to liberate the tungsten mineral. For this reason a mill must be equipped to handle any ore that may be offered or take the chance of running short of ore or of making a poor recovery from the ore that is treated.

When the district was first visited by the writers (January, 1919) to get data for this report, the milling capacity largely exceeded the amount of ore offered for treatment, and the mills were running only 8 or 12 hours a day. By thus running on a comparatively light feed a good extraction can be readily obtained by a properly designed mill. The milling capacity of the district seems equal to any demands, even with the mines operating at full capacity.

POWER FOR MINING AND MILLING.

Steam or electric power is used at the larger properties. The smaller properties use electricity or, where only a small plant is required and a power line would be too expensive, gasoline engines. The electric power is furnished by the Colorado Power Co., which has a hydroelectric plant in Boulder Canyon, a few miles above Boulder, the reservoir being just east of Nederland, between that town and Stevens Camp.

The price of electric power on a monthly basis is 4 cents per kilowatt hour for the first 100 kilowatt hours, 1.3 cents for the next 150 kilowatt hours, and 0.2 cent for all above this amount. There is an additional monthly charge of 50 cents per horsepower demanded.

GEOLOGY.

George[1] describes the general geology of the district as follows:

> The area is wholly within the pre-Cambrian belt, called, in a broad way, the Front Range. The nearest sedimentary rocks, except recent stream and lake deposits, are 3 miles to the east. The most important rock is granite, generally more or less gneissoid. Next in importance is a granitic gneiss, frequently grading into quartz-mica-schist and mica-schist. While the areas occupied by these two units are, in a large way, well defined, there are numerous bodies of gneiss within the granite and numerous bodies of granite within the gneiss. In a number of places there is no well-defined contact line between the two, but a band or zone in which the two rocks are mingled and in which there is frequently a gradual transition from one type to the other.
>
> Cutting the gneissoid granite and the gneiss are granite intrusions in the form of dikes and irregular bodies. In the western and northern parts are many dikes, ranging in composition from acidic porphyries to latites, andesites, diabase, and basalt.

The tungsten-bearing veins are mostly in the pre-Cambrian granite, in gneisses that are believed to be of sedimentary origin and at the contact of the two. "Crossings" and "junctions" are likely to be accompanied by an enrichment. The miners believe that the schistose part of the gneiss is not favorable for the finding of ore and that the best ore is found in the acid rocks rather than in the basic.

ORE MINERALS.

FERBERITE.

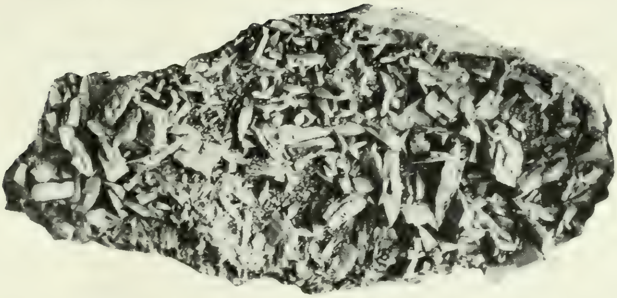
Tungsten, in Boulder County ores, occurs almost entirely as ferberite, although some hübnerite is found, especially near Ward. Scheelite is not of economic importance, but is occasionally found as small, almost microscopic fragments and is probably an alteration product from ferberite.

According to Hess,[2] ferberite "is that mineral of the wolframite series which is composed wholly, or almost wholly, of iron tungstate, and which, like other wolframites, crystallizes in the monoclinic system."

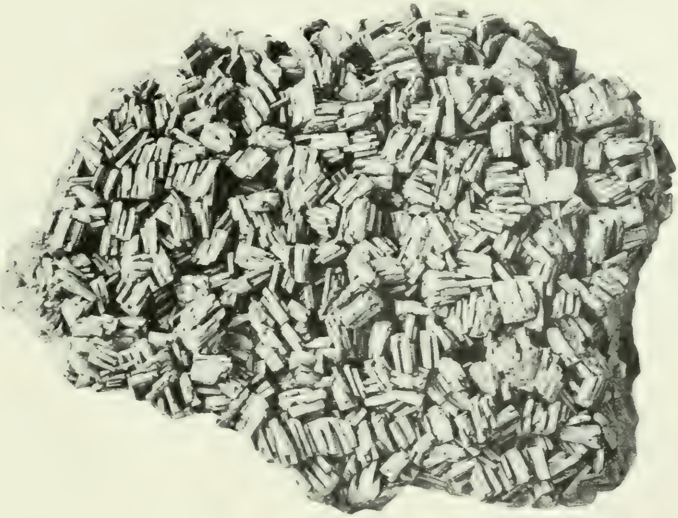
---

[1] George, R. D., The main tungsten area of Boulder County, Colo.: Colorado Geol. Surv., first report, 1908, pp. 7–103.

[2] Hess, Frank L., and Schaller, Waldemar T., Colorado ferberite and the wolframite series: U. S. Geol. Surv. Bull. 583, 1914, p. 7.

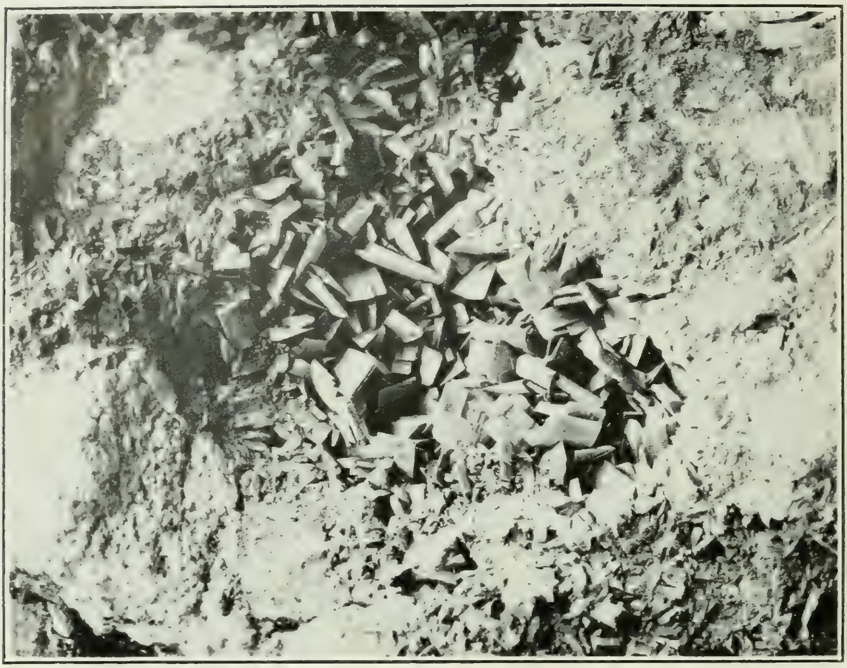


A. WEDGE-SHAPED FERBERITE CRYSTALS FROM "CROW PATENT," NEDERLAND, COLO. NATURAL SIZE.

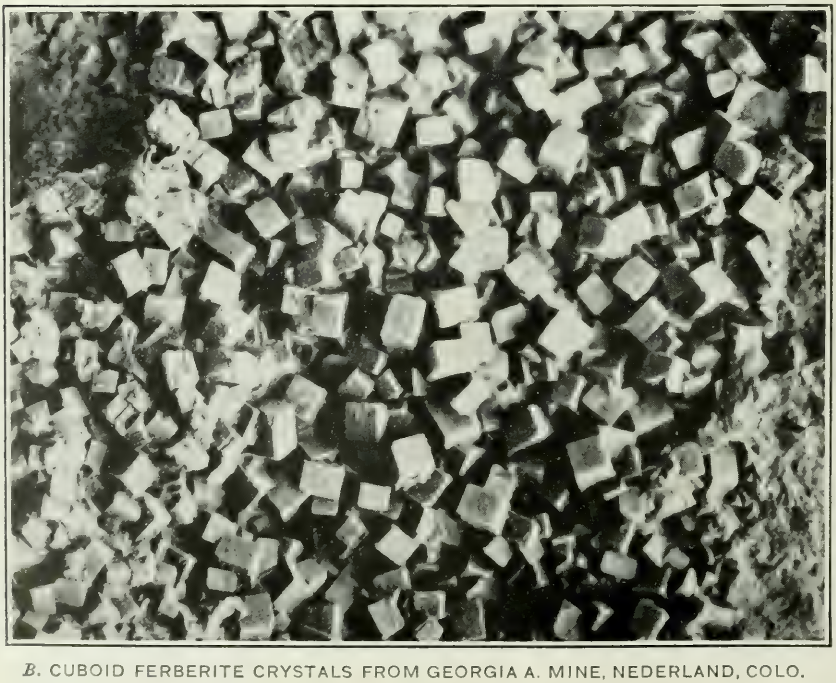


B. CRYSTALLIZED FERBERITE WITH ELONGATED, RHOMBIC CRYSTAL FACES, FROM NUGGET MINE, GRIFFIN COUNTY, COLO. NATURAL SIZE.

C. FERBERITE SPECIMEN, WEIGHT 2,100 POUNDS, ON EXHIBIT AT THE NATIONAL MUSEUM, WASHINGTON, D. C.



A. WEDGE-SHAPED FERBERITE CRYSTALS FROM HOOSIER MINE, NEDERLAND, COLO. ENLARGED TWO DIAMETERS.



B. CUBOID FERBERITE CRYSTALS FROM GEORGIA A. MINE, NEDERLAND, COLO. ENLARGED TEN DIAMETERS.

Except for its occurrence in the Boulder district, ferberite is comparatively rare, and in most places where it is found it occurs in small quantities only.

Ferberite, when pure, has a composition that may be expressed by the formula $FeWO_4$, corresponding to a content of tungstic oxide (WO_3) of about 76 per cent. Its specific gravity, determined on selected crystals, is 7.499, and its hardness about 5. Most of the ferberite in the Boulder district is jet black, but in a few places it is brown; the crystals and cleavage faces are usually lustrous black. The streak is characteristically chocolate-brown. Like other wolframites, ferberite crystallizes in the monoclinic system. The cleavage along *b* is perfect, and some specimens show a parting parallel to *a*.[3] The mineral is brittle with an uneven fracture, and is opaque, even in thin sections, as prepared for microscopic examination. A splinter of pure ferberite fuses to a crystalline nonmagnetic globule, but some of the ferberite from the Rogers tract is almost infusible before the blowpipe and is strongly magnetic after heating. The mineral occurs as wedge-shaped crystals, coarse to finely granular, and in the variety of ore locally known as "hornstone" the crystals are so intimately associated with quartz as to look like a stain; very commonly small crystals are coated with foreign material. Ferberite is very resistant to weathering; hence it has formed placer deposits that have been worked successfully. It is only very slightly soluble in acids. Some typical forms of ferberite are illustrated by Plates I and II.

QUALITATIVE TEST FOR TUNGSTEN.

Ferberite may sometimes be confused with magnetite, but differs from that mineral in color of streak and in being nonmagnetic toward a permanent magnet. The presence of tungsten may be confirmed as follows:

Grind the material to be tested very fine and boil with concentrated hydrochloric acid for about five minutes. Sulphuric acid may be used, but longer boiling is required. Nitric acid should not be used. After the material has settled, a fine yellow powder of tungstic acid is usually seen. Upon the addition of granulated zinc or tin a characteristic beautiful blue color is produced, which may be followed by violet and brown.

CHARACTERISTICS OF THE ORE.

Hess[4] describes the Boulder County ore as follows:

> The amount and character of the gangue in the veins differ greatly in different parts of the field. Quartz, the universal vein mineral, occurs in

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[3] Dana, E. S., System of Mineralogy, 6th ed., p. 983, 1909.

[4] Hess, Frank L., and Schaller, W. T., Colorado ferberite and the wolframite series: U. S. Geol. Survey Bull. 583, 1914, pp. 10–11.

smaller quantities in the ferberite veins than in most veins. Only a very little visibly crystallized quartz in the ferberite veins has come to my attention. There is, however, in most if not all of the veins of the northeastern part of the field, and in many of the wider veins of the southwestern part of the field, a very fine-grained gray or brown quartz, known as "bone," which has a fracture very much like that of chalcedony and which is largely a replacement of the country rock. The ferberite in the northeastern part of the field appears to be less well crystallized than in the southwestern half. It occurs in some of the veins in minute particles, mixed with quartz, so that in many places the ore is difficult to concentrate, although the total percentage of WO_3 may be as high or higher than in ores which are easily and profitably worked.

In the southwestern part of the field the narrower individual veins are made up almost wholly of ferberite, which has grown from both sides of the crevices and forms combs of small crystals that coalesce at their bases. The combs are of fairly uniform thickness, so that although in the narrower crevices they may have met and grown together, in the wider cracks they form bristling crusts of crystals on each side. In places these crystals are clean and bright, but generally very small, from one to three thirty-seconds of an inch (1 to 2 millimeters) across. Most of the crystals are covered with a coating of impure chalcedony, which in some specimens is mixed with opal and in others contains much iron. The coating generally includes small crystals of ferberite, which are, of course, of a later generation than those on the walls. Some vugs 3 or 4 inches across are entirely filled with such a mixture.

In places the country rock, instead of being sheeted, is crushed into smaller, more nearly equidimensional fragments, which may not be over one-eighth inch (3 millimeters) in diameter. Ore in which fragments of rock no larger than half an inch (13 millimeters) across, are embedded in ferberite, is popularly known as "peanut" ore, from its resemblance to peanut candy. The fragments of the breccia vary greatly in size, and when the fragments are larger the breccia is characterized by vugs lined with ferberite crystals. Many of the veins have been opened several times, so that the ferberite itself is brecciated.

MINERALS ASSOCIATED WITH THE FERBERITE.

In the ferberite veins of the main part of the field there are few associated minerals except quartz. Near the gold-silver bearing areas there is, of course, a mixture of the minerals of the several vein groups. Hess and Schaller[5] have described in detail the minerals associated with ferberite taken from the Boulder district. These minerals comprise adularia, calcite, chalcedony, chalcopyrite, galena, gold and silver, hübnerite, wolframite, hamlinite, hematite (specular), limonite, magnetite, molybdenite, opal, pyrite, quartz, sheelite, sphalerite, and sylvanite. For a detailed account of the occurrence, association, and amounts of these minerals the reader is referred to the report cited.

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[5] Hess, F. L., and Schaller, W. T., Colorado ferberite and the wolframite series: U. S. Geol. Survey Bull. 583, 1914, pp. 12–17.

CONDITIONS GOVERNING MILLING PRACTICE.

Most of the mills in the district attempt to produce a concentrate containing 60 per cent tungstic oxide, although some that have refinery connections can market a product carrying as low as 40 per cent. The grade of concentrates produced may be considered according to the requirements of the three main uses to which they are put: (1) Ferrotungsten, (2) tungsten powder (metallic tungsten), (3) tungstic oxide (tungstic acid).

As noted above, the general standard is that the concentrates shall contain at least 60 per cent tungstic oxide. As pure ferberite contains 76 per cent tungstic oxide, the margin for obtaining the desired result by wet concentration may seem ample at first sight, especially as the specific gravity ferberite is about 7.5 and that of the gangue is between 2.5 and 3. But the ferberite is very brittle, slimes easily, and the great problems of milling ferberite ores are efficient handling of the slimes produced and crushing so as to liberate the ore particles with a minimum amount of sliming. An adjustment of the concentrating devices to produce a high-grade product results in a lower recovery, whereas attempts at a high recovery result in a comparatively low-grade product. This fact must be kept in mind when recoveries are considered; both the recovery and the grade of the product made should be known. A mill reporting a recovery of 75 per cent may seem to be doing poorer work than another reporting 90 per cent, but the first mill may be producing a concentrate of so much higher grade that comparatively it is doing excellent work.

By hand sorting some ores a small amount of 60 per cent ore may be obtained, but only rarely is a product better than 50 per cent made. Hand sorting usually does not pay, as the greater part of the ore remains to be crushed and concentrated.

The difference in amenability to treatment among ores from different localities, and even among ores from different parts of the same vein, adds to the difficulty of concentrating Boulder County ores. A low-grade ore may be more valuable than one of higher grade because it is easier to concentrate and yields a higher recovery. This difference depends entirely upon the physical association of the ferberite with the quartz. In some ores the ferberite crystals may be easily freed from the quartz; in treating such ores fine crushing is not necessary and sliming losses are greatly reduced. These ores grade imperceptibly into those locally known as "hornstone," so called from the blending of white and black, resembling that often seen near the tip of the horns of cattle. Such ores seem to be chalcedony with only enough ferberite to give a dark color. The appearance indicates a simultaneous deposition of the ferberite and quartz, with neither one impregnating the other.

This difference in mill-saving quality is strikingly brought out by the examination of results obtained by testing ores of different character. Several mill tests to illustrate this point are given by Victor G. Hills.[6] The tests were made in February, 1905, and the results are shown in Table 1.

The lots were tested on the same day, with the same tables, operated by the same men, and hence show unmistakably the difference in the nature of the ores:

TABLE 1.—*Mill tests made in 1905.*

Test number	1	2	3	4
Contents of crude ore, % WO_3	11.66	14.83	14.14	5.31
Contents of coarse concentrates, % WO_3	67.64	60.10	35.60	28.32
Contents of slime concentrates, % WO_3	66.60	64.40	44 20	49.52
Contents of total mixed concentrates, % WO_3	67.59	60.20	35.90	29.40
Per cent saved	83.40	72.60	52.70	32.20
Per cent of concentrates caught as slime	4.80	3.30	4.50	5.33
Per cent of WO_3 saved in the slime	4.65	3.53	5.50	9.11
Concentration ratio	6.95	5.60	4.82	17.18

Numbers 1 and 2 are from the west side of the district and numbers 3 and 4 are from the east side.

A selected piece from lot No. 3, without visible quartz or other impurity, apparently a solid mass of amorphous or cryptocrystalline ferberite, had a specific gravity of 3.01 and analyzed as follows:

Analysis of apparently amorphous ferberite.

	Per cent.
WO_3	30.96
Iron	10.20
Manganese	0.82
Silica	34.44

From an inspection of this analysis, in connection with columns 3 and 4 above, it is evident that a good grade of concentrate can be made from this ore only by extremely fine crushing, and then the slime loss must be abnormally high. Even then it is doubtful whether a 60 per cent product could be made.

MILLING PRACTICE.

CAPACITY OF TUNGSTEN MILLS.

The capacities of tungsten mills are not expressed by the number of tons treated in 24 hours but by the amount of tungstic oxide produced. The standard used in marketing tungsten is usually the "unit" 1 per cent of a ton, or 20 pounds. An ore carrying 5 per cent WO_3 is said to contain five units (100 pounds WO_3); and one carrying 60 per cent, 60 units (1,200 pounds WO_3). Obviously there is a great difference in two mill-runs of 25 tons each, when one contains

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[6] Hills, Victor G., Tungsten mining and milling: Proc. Colorado Sci. Soc., vol. 9, 1908–1911, p. 140.

5 per cent WO_3 and the other 20 per cent WO_3, although the tonnage is the same; the second run contains four times as many units treated as the first. The capacity of a mill in tons must state also the grade of ore.

EARLY PRACTICE.

In early development of this district the ores were concentrated in stamp mills designed for handling gold ores. Although the crushing equipment of these mills was practically unchanged, slime tables were added and the classifying and dewatering devices were modified, so that the table work was new. As was to be expected, such mills were not at all efficient in treating the ferberite ores. The average recovery prior to 1907 was probably about 50 per cent, and a recovery of 60 per cent was considered good work. However, this was not poor mill practice when the conditions under which the mills operated are considered. The market was uncertain and the prices paid for the concentrates were never very high. Many of the ore deposits were relatively small and the finances of many of the operating companies permitted only a minimum development. The use of existing mills was cheaper than the erection of new ones of better design as future conditions might not warrant the expenditure.

PRACTICE AT WOLF TONGUE MILL IN 1905.

A description of one of the old stamp mills, the Wolf Tongue mill at Nederland, is given by Van Wagenen.[7]

> The ore is dumped into bins from the wagons, thence over 2-inch grizzleys, through a 7 by 10 Blake crusher to a 20-stamp battery, the stamps of which weigh 1,000 pounds, drop 6 inches, 90 times a minute, through a 20-mesh long-slot screen; thence by launder to a hydraulic classifier which makes three products. The coarse goes to two No. 5 Wilfley tables, the middlings to a No. 3 Wilfley, and the slimes to two other No. 3 Wilfleys.
>
> Tables Nos. 1 and 2 (the No. 5 tables) make four products—a finished concentrate; a first middling, which is returned to the head of the table; a second middling, which goes to the Wilfley slimers; and a tailing. Tables Nos. 3 and 4 make two products—a finished concentrate and a tailing for the slimers. There are five 12-foot Wilfley slimers. The slimes from the five concentrating tables are brought together in a tank and distributed to four of the slimers, each of which makes three products—a finished concentrate, a finished tailing, and a middling taken from the four last panels. The middling goes to the fifth slimer where two products are made—a concentrate and a tailing. The mill treats 25 tons in 12 hours. The concentration is 15 to 1.

FIRST MILL ERECTED SOLELY FOR TREATING TUNGSTEN ORES.

In the summer of 1907 the Clarasdorf mill was erected on Middle Boulder Creek, about 11 miles from Boulder, on the Rogers tract, for the concentration of the ores produced from that property. This was the first mill to be erected solely for treating tungsten ores. A view of the Rogers tract and the Clarasdorf mill is shown by Plate III, *A* and *B*.

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[7] Van Wagenen, H. R., Tungsten in Colorado: Frenzel Prize Thesis, Colorado School of Mines, 1905.

An excellent description of the ore-dressing practice during 1906 and 1907 is given by Hills.[8]

The mill of which the work is given below is that operated by the Colorado Tungsten Corporation. It is located in the city of Boulder, and was formerly known as the "Boyd Mill." There is a jaw crusher, ten 1,000-pound stamps, 4 standard Wilfley tables, 2 Wilfley slime tables, and 8 Monell slime tables, and stationary canvas. The table surface was large even when using all of the stamps; and the proportion of table area was sometimes increased by hanging up some of the stamps. Usually with ore reducing 10 or more to 1 all of the stamps were used, while with ore reducing 5 to 1, only five stamps were used with all of the tables, thus doubling the table area per ton of ore; and for other grades of ore stamps would be used in about the same proportion. With 10 stamps the capacity of the mill was a trifle more than 1 ton per hour. Experiments were made with screens of from 12 mesh to 40 mesh; different ores called for different sizes. Of the two veins producing the greater portion of the ore treated at this mill, 16 mesh proved the most efficient for one and 20 mesh for the other.

The pulp was classified and passed over the four standard tables. The coarse tailing from the first table was discarded at once, carrying usually about 0.4 per cent WO_3. The tailing from the second table was reground. The tailings from the third and fourth tables went each to a separate Wilfley slime table. The tailings from these two tables, mixed, went to four Monell tables. The tailings from these went to a settling spitzkasten, from which the coarse material went to two more slime tables and the slime to the stationary canvas. There were many changes from time to time in the methods of distribution and classification, but the above is the plan in use during the greater part of the last year. Owing to the poor condition of the building and machinery there would usually be only six or seven of the eight slime tables in operation at any one time.

During the last month of operation another large spitzkasten and two more slime tables were added, taking the finer material from the last classifier.

The crude ore, the coarse concentrate, the slime concentrate, the coarse tailing, and the slime tailing were each sampled for every lot of ore. A mill record book was kept having 14 columns as follows: (A) Number of run; (B) number of shaft; (C) gross weight on cars; (D) percentage of moisture; (E) crude ore, dry weight; (F) assay of crude ore; (G) pounds of tungstic acid in ore; (H) pounds of concentrates saved; (I) assay of concentrates; (J) tungstic acid saved; (K) portion of tungstic acid in clean-up belonging to this lot; (L) total tungstic acid saved; (M) percentage saved; (N) ratio of concentration.

There were also forms for daily and monthly reports.

There is a record of 245 lots. Table 2 shows the best and the poorest of the economic results. They are selected and arranged to illustrate three points: The difference in character of the ores from different veins, the difference in the saving qualities between the oxidized and the deep-level ore from the same vein, and the difference in the mill saving, with different appliances on the same kind of ore.

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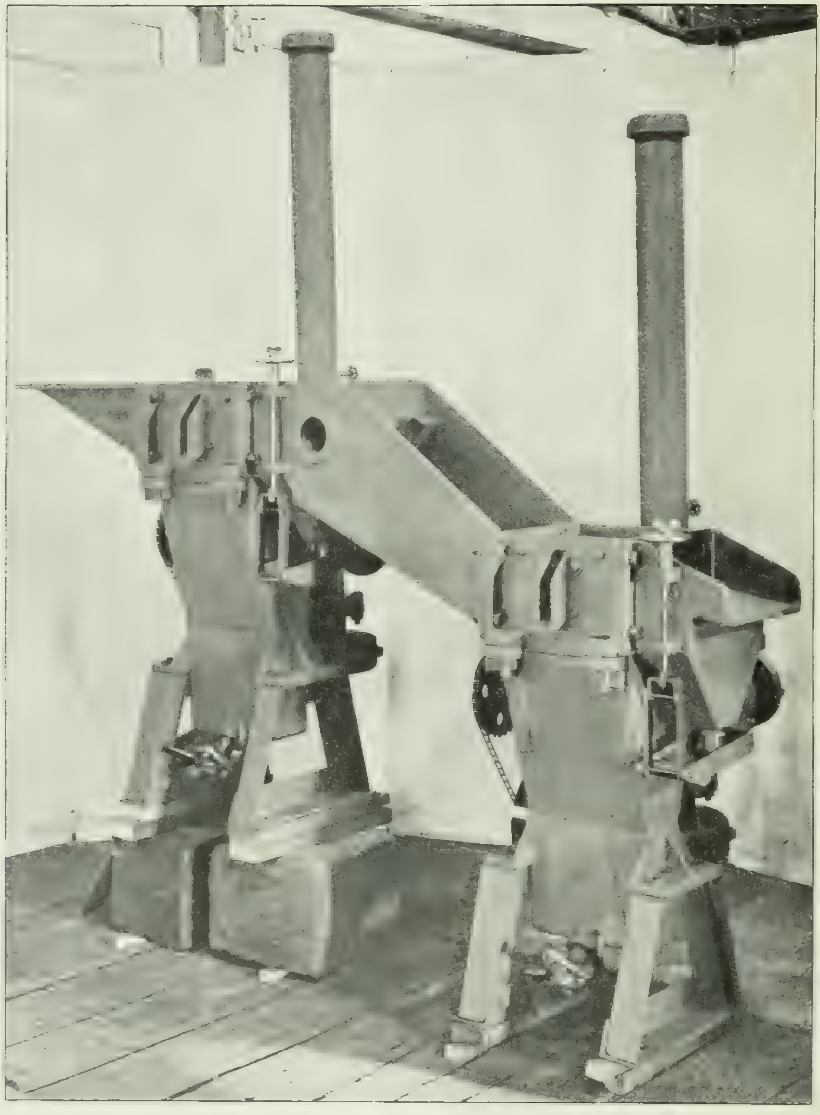
[8] Hills, Victor G., Tungsten mining and milling: Proc. Colorado Sci. Soc., vol. 9, 1908–1911, pp. 141–149.

A. ROGERS TRACT.

B. CLARASDORF MILL.

C. TRACT CONTAINING CONGER AND BEDDIG MINES.

D. MILL OF THE PRIMOS CHEMICAL CO.



TWO-COMPARTMENT RICHARDS PULSATING JIG.

TABLE 2.—*Representative mill work on tungsten ores during 1906 and 1907.*

Lot.	Mine.	Crude ore, per cent WO_3.	Concentration ratio.	Concentrates, per cent WO_3.	Saving, per cent.
1	A	16.57	4.70	65.41	85.22
2	B	12.43	7.96	54.49	56.19
3	C	6.07	181.81	40.37	5.03
4	D	8.07	8.69	62.17	88.90
5	D	12.03	7.10	65.12	76.44
6	D	6.09	12.05	62.11	85.62
7	D	6.48	11.91	64.88	84.78
8	D	6.82	11.49	62.15	80.35
9	D	6.97	11.15	62.45	81.35
10	D	5.83	13.51	62.25	80.00
11	D	7.50	11.04	62.93	79.06
12	D	4.31	18.58	59.13	74.84
13	D	5.16	14.57	61.42	82.74
14	D	5.54	13.28	61.20	87.38
15	E	9.51	8.93	62.59	75.11
16	E	9.94	8.27	60.48	75.08
17	E	8.67	9.43	61.38	76.50
18	E	10.08	8.53	60.48	73.47
19	E	8.11	9.68	60.41	77.46
20	E	5.31	14.72	60.27	81.58
21	E	5.27	14.15	61.01	86.52

Lots 1 to 7 are oxidized ores and all others are from deep levels.

Lot 1 is one of the best showings made from a small vein with little development.

Lot 2 is from a vein near Boulder Falls and is an example of one of the best ores ever treated from the east side of the district.

Lot 3 is the poorest ore ever brought to the mill (lowest in quantity that could be saved). It came from the east side of the district. It is readily seen that while the amount of tungstic acid in the crude ore compares favorably with the average ore of the district, the ore was commercially worthless. There was not enough of it saved to pay the cost of running it through the mill. It shows how an engineer, depending on his assays, without mill tests, might report favorably on a worthless mine. This, I understand, has actually been done in this district.

Lots 4, 5, 6, and 7 are of partly oxidized ores, and lots 8, 9, 10, 11, 12, and 13 are deep-level ores from the same vein, worked under substantially the same mill equipment. No. 14 is the only lot from this vein treated after the latest additions to the mill and is from the deepest level—180 feet on the dip or 140 feet vertically below the surface.

Lots 15, 16, 17, 18, and 19 are from another mine, 320 feet deep, at that time—1907—the deepest mine in the district. These lots were treated under the same mill arrangements as lots 8 to 13.

Lots 20 and 21 are the same ore as lots 15 to 19, treated with the latest additions to the mill.

The tungstic acid value of the several products, when working on normal deep-level ores, was usually as follows:

	Per cent.
Standard tables	62 –64
Wilfley slime tables	57 –59
Monell slime tables	35 –40
Stationary canvas	23 –27
Coarse tailings	.2– .6
Slime tailings	2 – 4

The slime tailing often varied widely with the ratio of concentration.

The output of the mill averaged above 60 per cent WO_3. Such few lots as carried below that figure were mixed with higher-grade lots so that nothing was marketed below the standard.

The lessons to be drawn from this exhibit are:

(*a*) That a comparison between the work of different mills is futile unless they were operating on the same kind of ore. Whenever any statement is made concerning the per cent of saving from any mill, three questions should at once be asked: First, from what part of the district was the ore produced? second, was it oxidized or unoxidized ore? third, what was the grade of the concentrate produced? I have heard that mills now operating in this district are marketing material down to a 30 per cent grade. It needs no demonstration to show that if this mill had been allowed to make any such low-grade product, the per cent of saving could have been readily increased.

(*b*) Oxidized ore concentrates a little better than the unaltered ore from the same vein. I regard this as due entirely to the difference in the physical condition of the gangue and the accompanying granite.

(*c*) The addition of the large settling and sizing spitzkasten, with two more tables and additional canvas surface, made a material increase in the saving, and, as would be expected, the additional saving was the greater with the ore which passed the finer mesh screen.

(*d*) The product of stationary canvas tables is low grade. It must be retreated on tables to secure a high-grade concentrate.

Table 3 gives some analyses of concentrates made at the Clarasdorf mill during 1907.

TABLE 3.—*Analyses of tungsten concentrates from Clarasdorf mill during 1907.*

Sample No	1	2	3	4	5	6	7	8	9
Tungsten oxide	67.99	59.62	59.52	58.21	56.84	48.44	38.46	38.59	52.38
Iron oxide	32.57	29.55	30.01	29.13	26.59	37.07	39.31	34.01	26.40
Iron suphide	....	2.57	2.09	2.34	2.55	.02	.51	2.59	3.25
Sulphur	....	1.37	1.11	1.24	1.36	.01	.27	1.38	1.73
Manganese oxide	1.02	.75	.76	.77	.75	2.65	3.10	2.67	.70
Phosphorus	Trace.	.01	.02	.01	.02	.01	.01	.01	.02
Silicon dioxide	8.32	8.42	7.54	9.56	11.25	11.51	18.61	22.13	17.25

These are mostly from the poorer grades of concentrate.

No. 1 is from the mine designated as mine "D" in the table of millwork. This vein produced, I believe, a better quality of ore than any that has so far been worked in the district.

Nos. 2, 3, 4, and 5 are from mine "E." They are of mixed concentrates and represent ores from the deepest workings.

No. 6 is from mine "B," near Boulder Falls. It was oxidized ore.

Nos. 7 and 8 are from veins at the east side of the district.

No. 9 is an analysis of a slime concentrate from one of the better veins near Nederland.

The following description of the Wolf Tongue mill, as it was in 1913, compared with Van Wagenen's description of it in 1905, shows the development of tungsten milling. Blake crusher and rolls have been substituted for stamps as primary crushers, jigs have been added, and the table work has been much improved.

PRACTICE AT WOLF TONGUE MILL IN 1913.[9]

The Wolf Tongue mill and power plant are adjacent to each other on Middle Boulder Creek, at Nederland. The ore is hauled from the various mines by wagons and dumped in four 15-ton ore pockets. Ore running better than 50 per cent WO_3 is shoveled to a 5 by 8 inch Sampson crusher set to 1 inch, which dumps to a chain-and-sprocket elevator with 4 by 4 by 6 inch cups and a 19-foot lift. This elevator, running at a speed of 88 feet a minute, dumps to a Vezin sampler, which makes a one-tenth cut, the sample reject going to a 4-ton bin, from which it is sacked and shipped.

The lower grade is shoveled to an 8 by 10 inch Colorado Iron Works Blake crusher, set to 1 inch and making 203 revolutions per minute. From the crusher it goes to a set of 14 by 32 inch MacFarlane cornish rolls, set to one-fourth inch and driven at a speed of 110 revolutions per minute by a 48-inch wooden "bull wheel" and friction. The rolls discharge to an elevator similar to the one described; this raises the ore 20 feet to a Vezin sampler, which makes a one-sixteenth cut, the reject going to an elevator which raises it 30 feet and chutes it to one of the three 30-ton bins, in which it is held until settlement is made with the lessee. These bins are provided in the mill with gates from which the ore may be chuted to the elevator which raised it to the bin and delivered through another chute to the jig bin, and on the outside with gates through which it may be unloaded and hauled away, if for any reason the lessee decides not to have it treated. All of the above machinery is driven by a 50-horsepower motor.

After settlement is made the ore is delivered to the elevator and chuted to a 20-ton bin, from which a plunger feeds it to the screen line, consisting of two 3 by 7 feet trommels with 6 and 12 meshes per inch. Each trommel sends its oversize to a two-compartment Harz jig. These jigs work through side and hutch, making concentrates in both compartments, that from the first compartment assaying 53 to 55 per cent and that from the second 25 per cent. They are sacked and shipped as separate products. A 15-horsepower motor drives the jigs and trommels.

The jig tailing goes to a 50-ton battery bin, from which it is fed by Challenge feeders to three of four five-stamp batteries. The stamps weigh 900 pounds each and drop 5 inches with even discharge, each stamp crushing 2 tons per 24 hours from ¼ inch through 18-mesh Ton-cap screens. The fourth battery is used for regrinding, as many stamps as may be necessary being dropped for this purpose. The even discharge is used to minimize the amount of slime produced. A 35-horsepower motor drives the batteries and two Frenier pumps mentioned later. The battery discharge goes to an 8 by 44 inch Frenier pump, which lifts the pulp 15 feet and discharges it to a tank, to which the undersize of the second trommel of the screen line flows by gravity.

On the table floor below the batteries are one Wilfley and five Card tables with speed and stroke as follows: 240 revolutions per minute, ¾ inch; 260 revolutions per minute, ½ inch; 270 revolutions per minute, ¼ inch; 270 revolutions per minute, ¼ inch; 285 revolutions per minute, ¼ inch; 258 revolutions per minute, ¼ inch. The last table is a Wilfley, and is used for treating the recrushed product. Classification is by means of three small shaking screens designed by William Loach, manager of the Wolf Tongue, and peculiar to this plant. The screen consists of an eccentrically operated galvanized-iron hopper with a screen inside, so that the oversize is discharged to the table and the undersize passes out of the bottom of the hopper and on to the next screen.

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[9] Palmer, Leroy A., Tungsten in Boulder County, Colo.: Eng. and Min. Jour., vol. 96, July 19, 1913, p. 99.

The first three tables are provided with these sizers, as follows: 20-mesh, 240 ½-inch strokes; 40-mesh, 260 ¾-inch strokes; 90-mesh, 280 ¾-inch strokes. They are found to give satisfaction.

The first five tables, the Cards, make two grades of concentrate, a first grade running from 62 to 65 per cent, and a second grade running from 25 to 30 per cent. All tailing from the first table is reground, but the second and third make a rejection. The fourth and fifth treat the undersize of the last shaking screen and send all tailing to the slimers. All middling from the first three and last tables goes to an 8 by 44 inch Frenier pump, which elevates it 21 feet to the regrind battery, where it is passed through a 60-mesh screen and sent to the Wilfley table, which makes only second-grade concentrate and middling. A 20-horsepower motor drives the tables and sizers.

Slime is treated on three Monell slimers. This is a comparatively unknown machine, but has given good results on this ore. It consists of a rubber-edged canvas belt with an exposed surface of 5 by 18 feet and a transverse slope of 2 inches. Feed is discharged lengthwise for a length of 12 feet along the upper edge of the belt from a perforated pipe and wash water is fed on at the concentrate end. It has a belt speed of 1 foot per minute and receives 260 ½-inch strokes longitudinally from an eccentric without differential motion. The slimer feed consists of the middling of the fourth and fifth Card tables and the overflow of the table-feed tank, one slimer to each of the above products. The slimers make second-grade concentrate and the tailing is sent to a double-compartment concrete sump, 18 by 18 by 4 feet. While this tank is filling, quicklime, in the proportion of 20 pounds per 100 tons of tailings, is added to settle the colloids, which otherwise would remain in suspension almost indefinitely. As many of these fine particles consist of valuable mineral too fine to be recovered by any process yet devised, it is sometimes found advisable to ship the slimer tailing as second-grade concentrate. All tailing of ore running over 20 per cent WO_3 is treated in these tanks and either shipped or pumped back by an 8 by 44 inch Frenier pump and re-treated. A 15-horsepower motor drives the slimers, Frenier pump, 2-inch centrifugal pump for delivering slime concentrate to the drier, and a small compressor for cleaning the motors.

The concentrates are dried and shipped to the Firth-Sterling Steel Co., McKeesport, Pa., where their principal use is in the manufacture of ferrotungsten. First grade is settled for at the market quotation and second grade at about 5 per cent better than the same grade in ore.

Machines.	Number of motors.	Horsepower.
1 crusher, 1 set rolls, 2 elevators, 1 sampler	1	50
2 trommels, 2 jigs	1	15
2 pumps, 20 stamps	1	35
6 tables, 3 sizers	1	20
3 slimers, 2 pumps, 1 compressor	1	15
Total horsepower		135

Tailing is settled consecutively in three ponds before the overflow is discharged to the creek. The mill operates 12 hours per day with superintendent, foreman, sampler, jigman, tableman, weigher, and a mechanic who makes repairs in the mill and attends to the power house. The extraction is claimed as from 88 to 90 per cent. This is possible when the slime tailing is shipped and the only rejection made is from three of the Card tables.

GENERAL MILLING PRACTICE IN 1916.

In an article by Wolf and Barbour[10] the general milling practice of the district as carried on in 1916 is described as follows:

> The ore is passed over a 2-inch grizzly, from which the undersize is passed to a stamp battery. The oversize is crushed and delivered to the stamps. The stamps used vary in weight from 750 to 950 pounds each. The number of drops per minute ranges from 70 to 90. The drop is usually low and ranges from 4½ to 6 inches, and from 12 to 20 mesh screens are used. The pulp from the batteries is classified and distributed to Wilfley or Card tables, upon which the first concentrate is made. The tailings are frequently classified and again delivered to tables, or sometimes Frue vanners. Both 4 and 6 foot vanners are in use. The tailings from the second concentration on either tables or vanners are sometimes recrushed in a Huntington mill with a 60-mesh screen, and the product is treated on slime or canvas tables. This outline is subject to considerable modification in different mills. In some of the plants ordinary Harz jigs are employed to advantage and revolving screens are used for sizing. Both Wilfley and Card tables are in use, but the latter seem to be the favorite.

SUMMARY OF MILL PRACTICE.

Present milling practice for the tungsten ores of Boulder County is characterized by stage crushing and screening; each reduction is followed by concentration by means of the devices best adapted to each size. As a rule, the first concentration is done by jigs, either the Harz type or the Richards pulsating jig. The feed to these coarse jigs varies in size from that passing a 4-mesh screen to that which is retained by a 20-mesh screen. Probably the average size of the coarse concentrates is about 10 mesh. Jig tails are reground by rolls, and after screening may be treated in "fine" jigs. These are of the launder type of Richards jig and produce a concentrate which averages about 20 mesh in size. Where there are no "fine" jigs, the reground tails from the coarse jig are treated on "coarse" tables. Table tails are reground and prepared for the slime tables; table middlings may be reground and put into a middling circuit, or held for separate treatment when enough accumulates.

Crushing is carried to such an extent that when the tailings are discharged practically all of the mineral has been liberated. This means that a large proportion, which varies with the nature of the ore, will pass a 100-mesh screen. Screening out a portion of the sand table tailing low in tungsten and removing it from the mill circuit might pay, as this would lighten the load on the slime-treating devices, but the loss of tungsten might be overbalanced by the cost of saving it.

After the ore is crushed to three-fourths to 1 inch by means of jaw-crushers, rolls are used for preparation of the mill feed. Ball mills of various types are used for regrinding, and in one mill, the Wolf Tongue, stamps are used to regrind the jig tailing.

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[10] Wolf, Harry J., and Barbour, Percy P., The Boulder County tungsten district, Colo.: Eng. and Min. Jour., vol. 102, July 22, 1916, pp. 165–169.

Within the last few years stamps have been abandoned for fine crushing and jigs have been introduced to save the coarse mineral. In the stamp batteries coarse ferberite slimes readily because of its brittleness, and is subjected to undue crushing as its high specific gravity causes it to settle back on the mortar.

Canvas tables are installed in all of the mills visited with the exception of the Vasco, but the canvas plant in the mill of the Tungsten Products Co. was not in use. The use of canvas tables is said to result in a recovery amounting to about 10 per cent of the total. However, they make a low-grade product, about 20 per cent WO_3, which requires cleaning on tables.

Extractions, as shown by company reports, vary from 75 to 90 per cent, according to the grade and character of the ore treated and the grade of the concentrate made. Possibly the best extraction under favorable conditions when a 60 per cent product is made is 90 per cent.

GRADE OF CONCENTRATES.

The concentrates are of two kinds—"crude" and "high-grade." The crude concentrates are utilized in the manufacture of ferrotungsten and tungstic oxide. These two products are basic for producing all compounds containing tungsten. All ferrotungsten is used as a means of introducing tungsten into ferroallows, whereas tungstic oxide is used to produce tungsten powder and chemicals. Tungsten powder is extensively used as a means of introducing tungsten into ferro and other alloys.

The high-grade concentrate—60 per cent WO_3 or more—is desirable for the manufacture of ferrotungsten. In making tungstic oxide by the hydrochloric-acid process the material used may range from 20 to 40 per cent WO_3, but in using the soda fusion method, a higher grade, 40 to 50 per cent, is desired, although at the plant of the Black Metal Reduction Co. ore mining as low as 12 per cent is used in a fusion process.

SAMPLING.

The usual sampling device is the Vezin sampler, set to cut from one-tenth to one-twentieth of the ore stream, or two Vezin samplers may be used, making a final cut of one-fortieth. The ore is crushed so that it passes a screen ranging from 4 to 8 mesh. The sample obtained by the Vezin sampler, if 300 pounds or less, is further reduced in size by sample crushers and rolls and is divided by hand by means of a sampler of the Jones-splitter type. If more than 300 pounds, the sample is again passed through the Vezin. After being sampled the ore, if it is a custom lot, is retained in a separate bin, called the settlement bin, until a satisfactory arrangement is made with the seller.

Another form of sampling device is known as the chain and cup, in which cups are supported between endless traveling chains. The quantity removed as a sample may be regulated by varying the number of cups. The cups passing under the ore stream retain a portion, while the rest of the stream drops between the chains. After the sample is taken it may be coned and quartered or passed through a splitter, and suitable reduction in size made by the sample crusher and rolls.

The final sample for assay is ground so that it passes 80 mesh and is about 1 pound in weight. This is split into the necessary number of assay pulps.

ASSAY OF ORES AND CONCENTRATES.

STANDARD METHOD.

The following method, developed by Hugh F. Watts, of Boulder, is used throughout the district as the standard for control and umpire work:

In preparing the sample for assay an amount slightly in excess of the weight desired is ground to a very fine powder by means of a mechanical agate mortar. Where a number of samples are to be prepared this machine is indispensable.

One gram of ore is weighed into a 250-c. c. beaker and treated with 60 c. c. HCl, or with ores carrying 5 per cent or less WO_3, 2 grams are weighed into a 150-c. c. beaker and treated with 40 c. c. HCl. Stir, cover with a watch glass, and digest for about two hours on a hot plate until the acid has evaporated to 10 or 15 c. c. Remove from hot plate and break up crust: add 40 c. c. of a mixture of one part HNO_3 to 10 parts HCl and digest again for one hour. Dilute with 50 c. c. H_2O, containing 1 c. c. HCl. Allow to settle and filter by decantation on a 12.5-cm. Swedish No. 2 or Whatman No. 30 filter paper. Wash three times with acid wash water (1 part HCl to 50 parts H_2O). To the residue in the beaker add 20 c. c. of a mixture containing 1,200 c. c. H_2O, 400 c. c. NH_4OH, and 20 c. c. HCl. Decant through filter into a No. 3 Coors porcelain crucible. Wash five times with a few cubic centimeters of the ammonia solution. Evaporate the filtrate to dryness, ignite, and weigh as WO_3. With low-grade ores it may be necessary to evaporate in a platinum crucible and treat the residue with hydrofluoric acid for the removal of silica.

In assaying Chinese ores, certain hübnerites, wolframites, and scheelites, after the ore has been treated as described above for ferberites, as much as 2 or 3 per cent of the total tungsten may remain with the insoluble matter. The residue is fused with the regular alkali carbonate mixture and leached with water; the iron and other residues are filtered off, and the filtrate, which contains the soluble tungstate, is titrated with nitric acid, added from a burette, until tungstate, is titrated with nitric acid, added from a burette, until to drive off CO_2 and the mercurous nitrate added, which precipitates tungsten as mercurous tungstate. As the ore had been previously treated with acids this precipitate will most likely be free from those interfering elements that are likely to follow tungsten, such as chromium, molybdenum, vanadium, tin, etc. After the addition of the mercurous nitrate the solution will still be slightly acid, and unless it is neutralized some tungsten will remain in solution. The solution is neutralized with Na_2CO_3 and heated to boiling; the precipitate is allowed to settle, filtered on a good grade of quantitative paper, and washed with water containing 2 per cent mercurous nitrate. The filter paper is then ignited in a platinum crucible and the WO_3 weighed. The contained silica can then be driven off by HF. Tin, if present, can be volatilized as stannic chloride by ignition with ammonium chloride. The mercurous nitrate may be prepared by digesting 2 or 3 ounces of mercury for about two hours with 25 c. c. of nitric acid (conc.) in 100 c. c. water, and allowing it to stand over night on a hot plate kept below the boiling point. This solution when diluted to about 400 c. c. will give a saturated solution with a minimum of free acid.

SPECIFIC GRAVITY METHODS FOR APPROXIMATE ANALYSIS OF ORES.

A specific gravity method for obtaining the approximate tungsten content of an ore is commonly used in the tungsten districts. The method used in the Boulder district is described by Hess as follows:[11]

> The Wolf Tongue Mining Co. originated a method which has been used by it and others on the ferberite ores of the Boulder field with excellent results, and the constants used there have been found serviceable in other fields. The mode of operation is as follows:
>
> The articles needed are a flask holding about 1,500 c. c. of water and scales weighing in grams up to 3 or 4 kilos. The flask is counterbalanced, then 1,500 grams of water is weighed into it and the height marked on the neck.
>
> For determinations, 1,300 grams of water is weighed into the flask and then dry ore is poured in until the water is raised to the 1,500 gram (c. c.) mark. This means, of course, that the ore occupies 200 c. c. and that an equal bulk of water weighs 200 grams.

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[11] Hess, F. L., Tungsten minerals and deposits: U. S. Geol. Survey Bull. 652, 1917, p. 71.

The weight of water in the flask, 1,300 grams, is subtracted from the total weight, and the difference, which is the weight of the ore, is divided by 200 grams, the weight of the water displaced, thus giving the specific gravity, which is compared with a table giving the equivalent percentage of WO_3.

At the Wolf Tongue mill the table has been elaborated so that weights may be directly read into percentages by referring to Table 4, as shown below.

The figures given in Table 4 are not exact specific gravities, but are close enough to give valuable data as to the probable metallic content of the ore. Such a method is applicable whenever the ore contains no other heavy minerals and the gangue is of fairly constant composition. Corrections would have to be made for other ores. For example, the specific gravity of the Boulder ferberite is 7.499, or, say, 7.5, and the specific gravity of the scheelite ore, if free from heavy minerals, such as galena, pyrite, and hematite, will be somewhat lower.

TABLE 4.—*Percentage of tungsten trioxide indicated by weights of 200 c. c. of ferberite ore plus 1,300 c. c. of water, in the Boulder field, Colo.*

Weight of ore and water (grams).	Specific gravity corresponding to weight of ore.	Specific gravity for given percentages of ore.	Percentage of ore.	Weight of ore and water (grams).	Specific gravity corresponding to weight of ore.	Specific gravity for given percentages of ore.	Percentage of ore.	Weight of ore and water (grams).	Specific gravity corresponding to weight of ore.	Specific gravity for given percentages of ore.	Percentage of ore.
1,815	2.575	....	....	2,050	3.725	3.717	32	2,280	4.900	....	....
1,820	2.600	....	....	2,055	3.750	3.761	33	2,285	4.925	4.933	53
1,825	2.625	2.650	....	2,060	3.775	....	....	2,290	4.950	....	....
1,830	2.650	2.650	....	2,065	3.800	3.805	34	2,295	4.975	....	....
1,835	2.675	....	....	2,070	3.825	....	....	2,300	5.000	5.008	54
1,840	2.700	....	....	2,075	3.850	3.850	35	2,305	5.025	....	....
1,845	2.725	2.724	1	2,080	3.900	3.899	36	2,310	5.050	....	....
1,850	2.750	2.748	2	2,085	3.925	....	....	2,315	5.075	5.088	55
1,855	2.775	2.772	3	2,090	3.950	3.948	37	2,320	5.100	....	....
1,860	2.800	2.796	4	2,095	3.975	....	....	2,325	5.125	....	....
1,865	2.825	2.821	5	2,100	4.000	3.997	38	2,330	5.150	....	....
1,870	2.850	2.847	6	2,105	4.025	....	....	2,335	5.175	5.177	56
1,875	2.875	2.873	7	2,110	4.050	4.046	39	2,340	5.200	....	....
1,880	2.900	2.899	8	2,115	4.075	....	....	2,345	5.225	....	....
1,885	2.925	2.925	9	2,120	4.100	4.094	40	2,350	5.250	....	....
1,890	2.950	2.951	10	2,125	4.125	....	....	2,355	5.275	5.266	57
1,895	2.975	2.979	11	2,130	4.150	4.155	41	2,360	5.300	....	....
1,900	3.000	3.007	12	2,135	4.175	....	....	2,365	5.325	....	....
1,905	3.025	3.035	13	2,140	4.200	4.211	42	2,370	5.350	5.355	58
1,910	3.050	3.063	14	2,145	4.225	....	....	2,375	5.375	....	....
1,915	3.075	....	....	2,150	4.250	....	....	2,380	5.400	....	....
1,920	3.100	3.096	15	2,155	4.275	4.267	43	2,385	5.425	....	....
1,925	3.125	3.129	16	2,160	4.300	....	....	2,390	5.450	5.444	59
1,930	3.150	3.162	17	2,165	4.325	4.323	44	2,400	5.475	....	....
1,935	3.175	....	....	2,170	4.350	....	....	2,405	5.500	....	....
1,940	3.200	3.195	18	2,175	4.375	4.383	45	2,410	5.525	....	....
1,945	3.225	3.228	19	2,180	4.400	....	....	2,415	5.550	5.553	60
1,950	3.250	....	....	2,185	4.425	....	....	2,420	5.575	....	....
1,955	3.275	3.263	20	2,190	4.450	4.448	46	2,425	5.600	....	....
1,960	3.300	3.296	21	2,195	4.475	....	....	2,430	5.625	....	....
1,965	3.325	3.329	22	2,200	4.500	....	....	2,435	5.650	5.639	61
1,970	3.350	3.362	23	2,205	4.525	4.513	47	2,440	5.675	....	....
1,975	3.375	....	....	2,210	4.550	....	....	2,445	5.700	....	....
1,980	3.400	3.395	24	2,215	4.575	4.578	48	2,450	5.725	....	....
1,985	3.425	3.432	25	2,220	4.600	....	....	2,455	5.750	5.745	62
1,990	3.450	....	....	2,225	4.625	....	....	2,460	5.775	....	....
2,000	3.475	3.471	26	2,230	4.650	4.643	49	2,465	5.800	....	....
2,005	3.500	3.510	27	2,235	4.675	....	....	2,470	5.825	....	....
2,010	3.525	....	....	2,240	4.700	4.709	50	2,475	5.850	5.851	63
2,015	3.550	3.549	28	2,245	4.725	....	....	2,480	5.875	....	....
2,020	3.575	....	....	2,250	4.750	....	....	2,485	5.900	....	....
2,025	3.600	3.588	29	2,255	4.775	4.783	51	2,490	5.925	....	....
2,030	3.625	3.629	30	2,260	4.800	....	....	2,495	5.950	5.957	64
2,035	3.650	....	....	2,265	4.825	....	....	2,500	6.000	....	....
2,040	3.675	3.673	31	2,270	4.850	4.858	52	2,505	6.025	....	....
2,045	3.700	....	....	2,275	4.875	....	....	2 510	6.050	6.060	65

CLASSIFYING AND DRYING THE CONCENTRATES.

The concentrates from different concentrating units are kept as separate lots, such as hand-sorted ore, coarse-jig concentrates, fine-jig concentrates, table concentrates of different quality, and slime concentrates.

For drying the concentrates most of the mills use an ordinary heating stove or salamander made of sheet iron with a grate for fuel and a large stack (fig. 2). The stove is surrounded by a jacket perforated at the bottom. Wet concentrates charged into the jacket come in contact with the hot stove. As they are dried they drop through the perforations onto the floor, where they are allowed to cool, and are then sacked. The ashes from these stoves are held and treated, which results in a recovery of concentrate amounting to as much as 6 pounds a day.

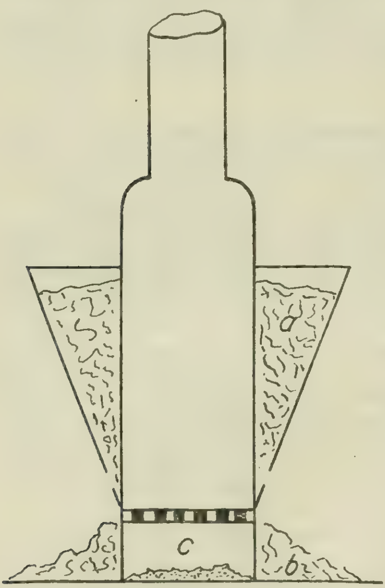


FIGURE 2.—Concentrate drier: *a*, Moist concentrate; *b*, dry concentrate; *c*, ash pit.

The mill of the Tungsten Products Co. uses steam tables for drying.

METHODS OF CONCENTRATION.

CONCENTRATION OF COARSE MATERIAL.

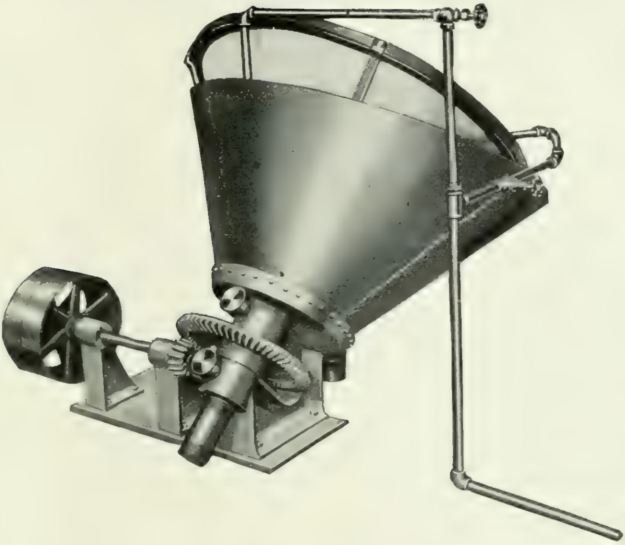
SORTING.

Hand sorting of the high-grade pieces, when practiced, is usually done in the stopes at the mine, although a small amount may be done at the mill. None of the mills, however, have any elaborate equipment for this purpose. Careful mining of the high-grade streaks, when encountered, obviates much sorting.

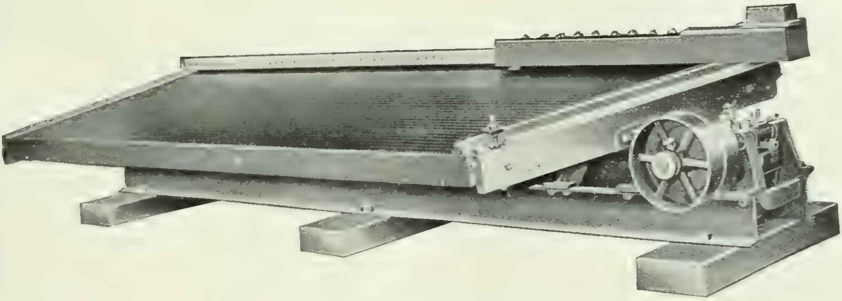
Sorting of the waste is not practicable, as exact distinction between the waste and a low-grade ore worthy of treatment is difficult. For instance, material carrying 1 per cent WO_3 may contain a large number of pieces of ore that surficially appear absolutely barren.

CRUSHING AND SCREENING.

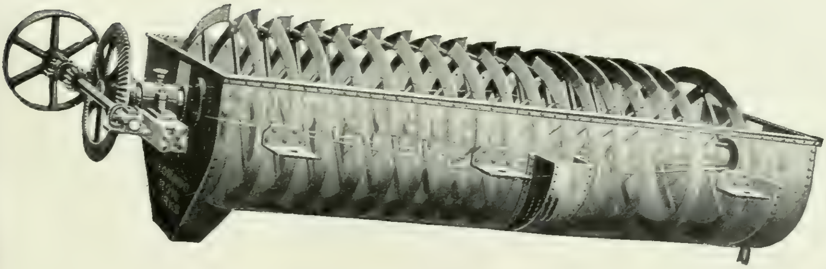
Screening begins with grizzlies having ½ to 1 inch openings. The grizzlies are set ahead of the primary crushers, which are all of the Blake type and range in size from 7 by 10 to 10 by 16 inches, the smaller size predominating. The size of the material delivered from



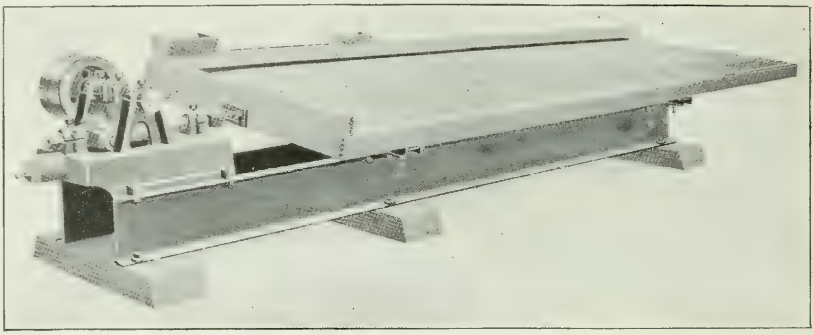
A. BUNKER HILL SCREEN.



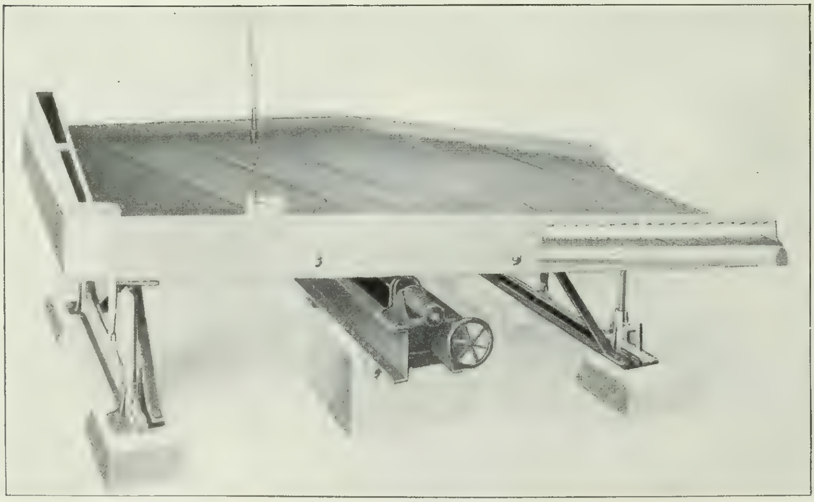
B. CARD CONCENTRATOR.



C. AKINS CLASSIFIER.



A. WILFLEY CONCENTRATOR.



B. DEISTER NO. 3 SLIMER.

these crushers ranges from 0.75 inch to 1.5 inches, but is generally 1 inch. The crusher product, which may or may not be screened, goes to rolls ranging in size from 12 by 20 to 16 by 36 inches, the usual size being 14 by 27 inches. Practice is about evenly divided as regards screening the crusher product, but where it is done trommels having from 4 to 8 mesh screens are used. In the Vasco mill the product from the primary crusher is sent to a secondary crusher with a stationary screen intervening, and thence direct to the primary rolls. The final roll product is generally about 4 mesh. The feed is then ready for sampling and storing in the settlement bins. All crushing and screening are done dry up this stage.

The next step is to screen by wet trommels having screens of 4 to 8 mesh, the oversize going to secondary rolls and the undersize, with or without further sizing by trommels, to coarse jigs. Jig tailings are then reground by rolls, except at the Wolf Tongue mill, which uses stamps.

Where the material is screened before sampling, trommels are run without water. For sizing the jig feed the trommels and impact screens are operated wet. Bunker Hill screens, ranging in size from 30 to 120 mesh, are employed extensively for preparing table feed. A view of a Bunker Hill screen is shown in Plate V, *A*.

JIGGING.

Practice in coarse jigging is about evenly divided between Harz jigs and Richards pulsating jigs. In size, the feed to the coarse jigs is about that passing a 4-mesh screen and retained by a 12-mesh screen. Screens are trommels, or of the impact type. At the mill of the Tungsten Products Co. the jig feed has been ground to pass an 8-mesh screen and the entire product is sent to the jigs without removal of the fine material.

Harz jigs and Richards launder-type pulsating jigs are used for jigging material about 20-mesh in size.

The coarse jigs make three products—concentrate, hutch, and tailing; and the fine jigs, two—concentrate and tailing. The hutch product may be retreated on jigs and tables, or it may be a finished product. Tailings are reground for sand-table feed.

Plate IV (p. 19) shows a two-compartment Richards pulsating jig.

TABLES.

For treating sands Wilfley and Card tables are used. A Card table is shown in Plate V, *B*, and a Wilfley in Plate VI, *A*.

Sand tables make three products—concentrate, middling, and tailing. The middling is held for separate treatment or reground. The tailing is classified in an Akins classifier, and the coarse is reground in ball mills.

CONCENTRATION OF THE FINE MATERIAL.

Concentration of the fine ferberite is accomplished by slime tables and stationary canvas tables, or, as they are locally known, "rag plants." The tables used are the No. 3 Deister, Deister-Overstrom, and Wilfley. The Monell and Wilfley box slime-tables that were used extensively several years ago have no place in the modern mills.

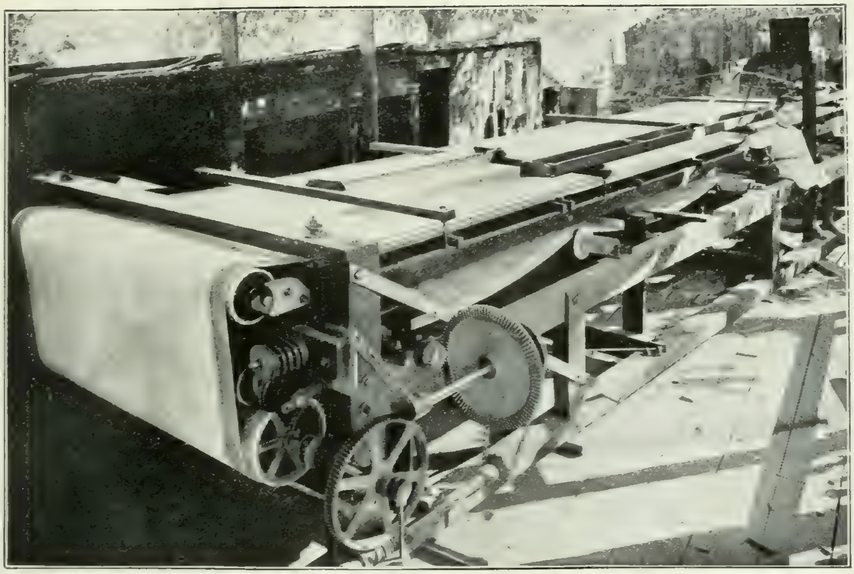
A new feature of the slime tables is a high-grade white enamel coating on the entire deck and riffle surface. Although some millmen believe this facilitates the treatment of ferberite slimes, the writers believe that it is of no value other than by affording a white background for the black mineral streak; it may help in defining the "point of cut," especially where the light is poor.

Slime tables may make two or three products—concentrate and tailing, or concentrate, middling, and tailing. The middlings may be reground and placed back in circuit, kept in a middling circuit, or held for retreatment when enough accumulates to warrant it. This, of course, is practically the same as a separate middling circuit. Tailings are generally thickened and sent to another set of slime tables, whose tailings may be further treated in this manner or sent to a "rag plant." Plate VI, *B*, shows a Deister No. 3 slimer.

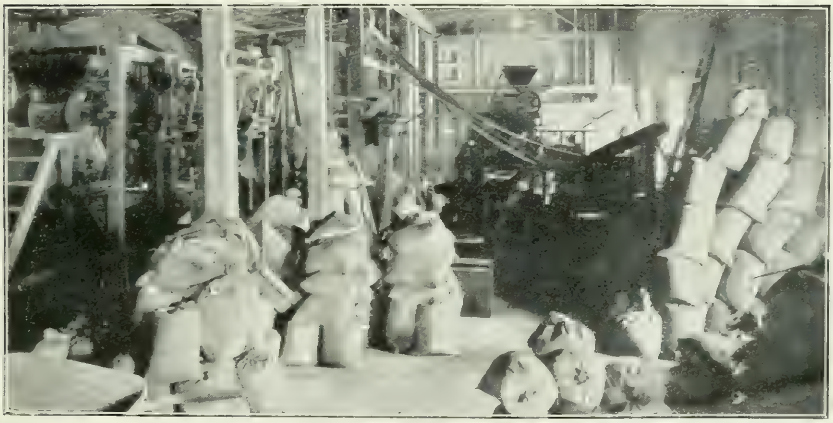
The "rag plants" consist of stationary tables covered with canvas and with a slope of about 0.75 inch to the foot. They are usually arranged in parallel in a series of groups. The pulp passes over the tables with a slow, rolling movement that permits the heavy mineral to settle into the interstices of the canvas. The tables are cleaned by shutting off the feed and washing down the surface with a hose. The concentrates are collected in suitable launders placed at the ends of the tables.

In size the tables are about 6 feet wide and 20 to 40 feet long. They require considerable mill room when treating a large feed, but are not expensive to maintain in repair when in continual operation and do not require much attention. The grade of the concentrate is low, about 20 per cent, and therefore the concentrates are retreated on slime tables.

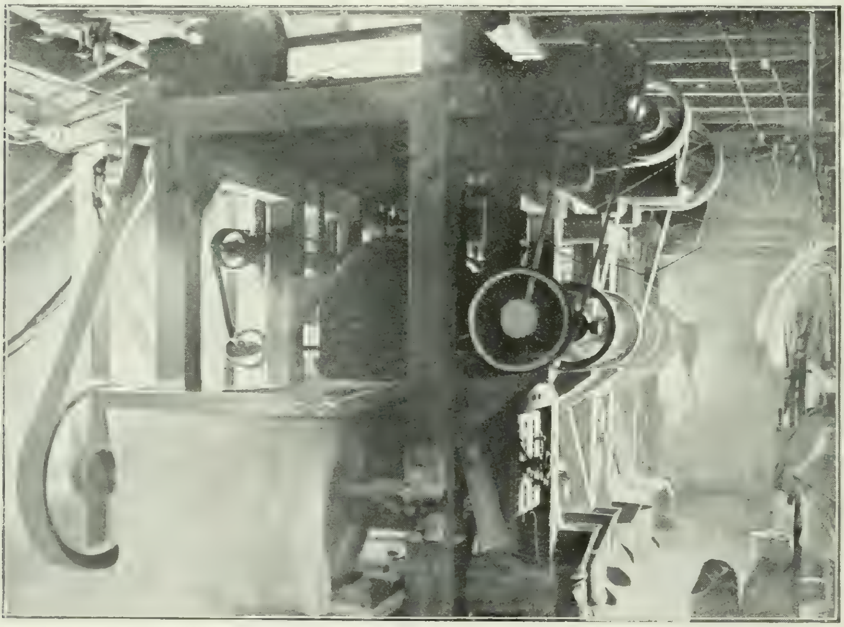
For classifying, settling boxes making several spigot products are valuable, as they do not introduce additional water into a pulp that should be kept as thick as possible. Some upward-current classifiers are used, but the extra water necessary is carefully watched. The Akins classifier is always used for separating sand from slime for ball-mill feed. Callow cones are in favor for thickening slime for tables. Plate V, *C*, represents the type of Akins classifier seen in the district.



A. MONELL SLIMER.



B. MAGNETIC SEPARATOR ROOM OF THE TUNGSTEN PRODUCTS CO.



PART OF MAGNETIC SEPARATOR OF TUNGSTEN PRODUCTS CO.

THE MONELL SLIMER.

The Monell slimer, shown in Plate VII, *A*, was extensively used in the mills of this district several years ago, and is not used much elsewhere. Parmelee[12] describes it as follows:

> It is a slime concentrator of the traveling-belt type, with a shaking movement in the direction of belt travel. Its principal features are the unusual length and slow travel of the belt and the large flat settling area afforded for the collection of fine material. The belt is 5 feet wide and the working surface is 23 feet long. The rate of belt travel is adjustable from 3 to 27 inches per minute, and is usually set at 18 inches. The number of vibrations varies from 160 to 180 per minute. Pulp is fed at one side of the belt and tailing discharged at the other.
>
> The feed is first received in a classifying box set about 2 feet above the deck of the table and near one end. Pipes from the several compartments of the box deliver the pulp to distributing launders arranged along the side of the table. The coarse grade is delivered near the end of the table, where it forms a bed for the collection of the finer grades that are delivered farther on. Suitable wash-water boxes are provided near the discharge end to wash off the sand and leave a clean concentrate.
>
> The belt travels on strips of redwood laid lengthwise of the table. The upper or feed edge is slightly raised to direct the flow of pulp across the belt, and the lower or discharge side is inclined downward to aid in discharging the tailing. These inclinations at the edges of the belt extend for a few inches only, and the large area between them is perfectly flat, thus affording an excellent settling surface.
>
> Owing to the manner of distributing the feed on the belt, a bed of high-grade mineral forms on its upper half and a less well-defined streak of lower-grade mineral on the lower half.
>
> When the belt passes through the collecting box the mineral accumulates in corresponding beds of high and low grade material, and the attendant keeps the two classes separate in clearing the box.

MAGNETIC SEPARATION.

One of the injurious impurities usually found in tungsten ores of the wolframite series in localities other than Boulder County is cassiterite, the only ore of tin. Its specific gravity is almost the same as that of wolframite, but as wolframite (ferberite) is affected by magnetic intensities that have no influence upon the casiterite, the ores can be separated with magnetic separators.

As the ferberite ores of Boulder County are practically free from cassiterite, magnetic separation is used to concentrate both crude ore and low-grade table concentrates.

Impurities, such as sulphur and phosphorus, the former usually occurring as pyrite and the latter probably as mineral hamlinite in the gangue, may be removed in this way. Concentrates from a magnetic separator will command a higher price than those that have not been thus cleaned.

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[12] Parmelee, H. C., Monell slimers: Met. and Chem. Eng., vol. 9, August, 1911, p. 409.

The magnetic treatment, especially when applied to the Boulder ores, has the disadvantages of dust losses due to the necessity for dry crushing and of inability to handle economically the finer sizes, to which much of the ore of this district must be crushed in order to free the ferberite. Also, the initial cost has to be considered, although a machine of the Wetherill type is simple and well constructed and runs with little attention and at a low cost after adjustment to the requirements of the ore treated.

The only installation of magnetic separators in the district is in the mill of the Tungsten Products Co., at Boulder, where are two Wetherill type "E" No. 3 machines, which have a feed belt 18 inches wide. They have three double-pole magnets, which are wound respectively for 100,000, 60,000, and 30,000 ampere turns. Magnetite, siderite, clean ferberite, and ferberite middlings are lifted in the order named, the pyrite, phosphorus minerals, and clean gangue pass into the tailing. For concentrating fairly high-grade ores (20 to 40 per cent), in which the ferberite is liberated without excessive crushing, magnetic separators are of value with a wet concentration plant. The fine material that the magnetic separators are unable to handle may be put into the wet mill circuit. Plates VII, *A*, and VIII, *A*, give two views of the magnetic separators at the mill of the Tungesten Products Co.

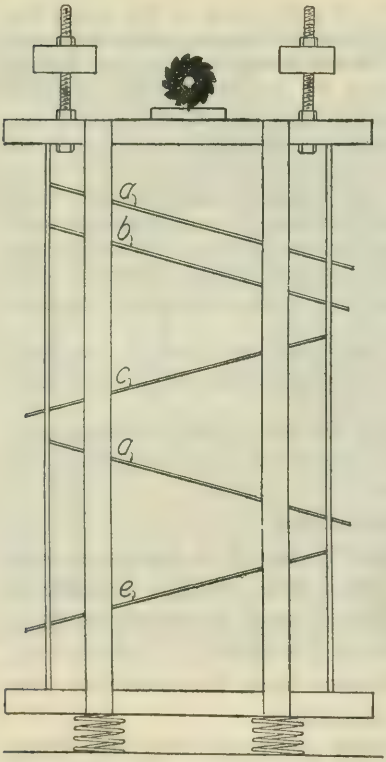


FIGURE 3.—Ellis screen: *a*, 20-mesh; *b*, 40-mesh; *c*, 60-mesh; *d*, 80-mesh; *e*, 100-mesh screen.

DRY SCREENING.

For preparing the feed to the magnets for close dry-sizing and for grading up products, screens of various types are used. At the Tungsten Products Co. mill is a screen devised by William Ellis, mill superintendent, shown in figure 3. It consists of a series of superimposed screens, 1.5 feet wide by 4 feet long, set at an angle of 14° in a suitable dust-proof housing. Vibration is imparted by a ratchet with 12 teeth, revolving 125 revolutions per minute, and imparting a total of 1,500 impacts a minute to the frame. The ratchet is keyed to a revolving shaft that carries the driving pulley. The tension upon the springs may be easily adjusted. Suitable chutes convey the screen products into separate bins. Another type of screen, called the Allen, that has been used in the district, utilizes several weighted pulleys attached to the driving shaft for imparting vibrations to the screens, which are supported in a frame by hickory legs or on springs. The Bland screen, described in another part of this bulletin under "The Grimm Concentrating Mill," is much like the Allen screen, but differs in the vibrating mechanism.

LOSSES.

The concentration loss in treating ferberite ores is due almost entirely to the difficulty of treating the slimes. The standard tables make a satisfactory high-grade product from the coarser sizes, about 20 to 80 mesh, and jigs from the larger sizes. The tailings from these devices vary greatly in value according to the nature of the ore treated. For ores in which the ferberite is coarsely crystallized, the tailings are low, as the valuable mineral is usually well liberated from the gangue; but in the "hornstone" ores the ferberite is so intimately associated with the quartz that a great amount of crushing is needed and a high tailing is inevitable. The amount of high-grade concentrates produced in treating the latter type of ore will be very low.

The ferberite is so much more brittle than the accompanying gangue that in crushing it is reduced to particles much smaller than the gangue particles, and although its specific gravity is higher, it is acted upon by the same forces and in the same way as is the gangue. The presence of the smaller size of the ferberite particles was demonstrated to the writers at the mill of the Rare Metals Ore Co., at Rollinsville, in observing the work of the Bland screen. (See p. 37.) The feed to the machine was a rag plant concentrate, carrying about 20 per cent WO_3. Three products were made on calibrated China silk fabric, as follows: Material retained on cloth with 0.004-inch openings (corresponding to Tyler screen 150 mesh); minus 0.004-inch plus 0.002-inch material, and minus 0.002-inch material (corresponding to Tyler screen 280 mesh). The latter product was very different in appearance from the feed, being black and resembled high-grade slime concentrate. According to S. B. Tyler, superintendent of the mill, this product usually assays between 40 and 50 per cent WO_3. Deposition of these products is described on page 42.

The slime losses may easily amount to 20 to 30 per cent of the valuable mineral content of the original ores, and where much "hornstone" is present, the losses may be larger. Unless slime tables or a "rag plant" is used the total recovery will be lowered. A "rag plant" or a set of slimers will save between 10 and 20 per cent of the tungsten in the original ore.

The results of the following screen analysis of a typical sample of tungsten-mill tailing shows how sliming effects losses:

TABLE 5.—*Distribution of tungsten losses in screen products from a typical sample of tungsten-mill tailing.*

Mesh.	WO_3 content.	Loss.
	Per cent.	*Per cent.*
20–40	0.63	2.0
40–60	.57	6.9
60–80	.375	7.0
80–100	.365	2.0
100–200	.275	10.1
Minus 200	1.41	66.0
	....	100.0

DESCRIPTIONS OF INDIVIDUAL PLANTS.

THE TUNGSTEN PRODUCTS CO.

The Tungston Products Co. owns and works the Luckie 2 mine in Boulder Canyon (Middle Boulder Creek), about 9 miles above the town of Boulder. In Boulder the company has a concentrator, a plant for making tungstic oxide, and a smelter for producing ferroalloys, the company handling custom ore as well as ore from its own properties. This is the most complete plant for mining and treating ferberite ores in the district, as it embraces all phases of tungsten production. The company has an excellent laboratory with facilities for research as well as for routine analytical work. The mill circuit is shown in figure 4.

This diagram and the others in this bulletin were made by the writers during their visit to the district in January, 1919. None of the mills visited had the graphic flow sheets brought up to date, so it was necessary to study out the circuit for each mill.

A striking feature of this concentrator is the excellent work done by the Harz jigs. These jigs (fig. 5) have been modified by the mill superintendent, William Ellis, according to the following ideas:

The partition between the plunger compartment and the screen compartment is arranged so that both compartments have the same width. This may be done either by moving the partition or by building up the sides. In the screen compartment the sides below the screen supports are filled in so that they are flush with the supports. In this way a more even pressure is exerted on the bed of the jig. The screen is of the same mesh as the trommel, whose undersize is the feed. For low-grade ores it may be necessary to use a screen with slightly smaller openings than the trommel in order to

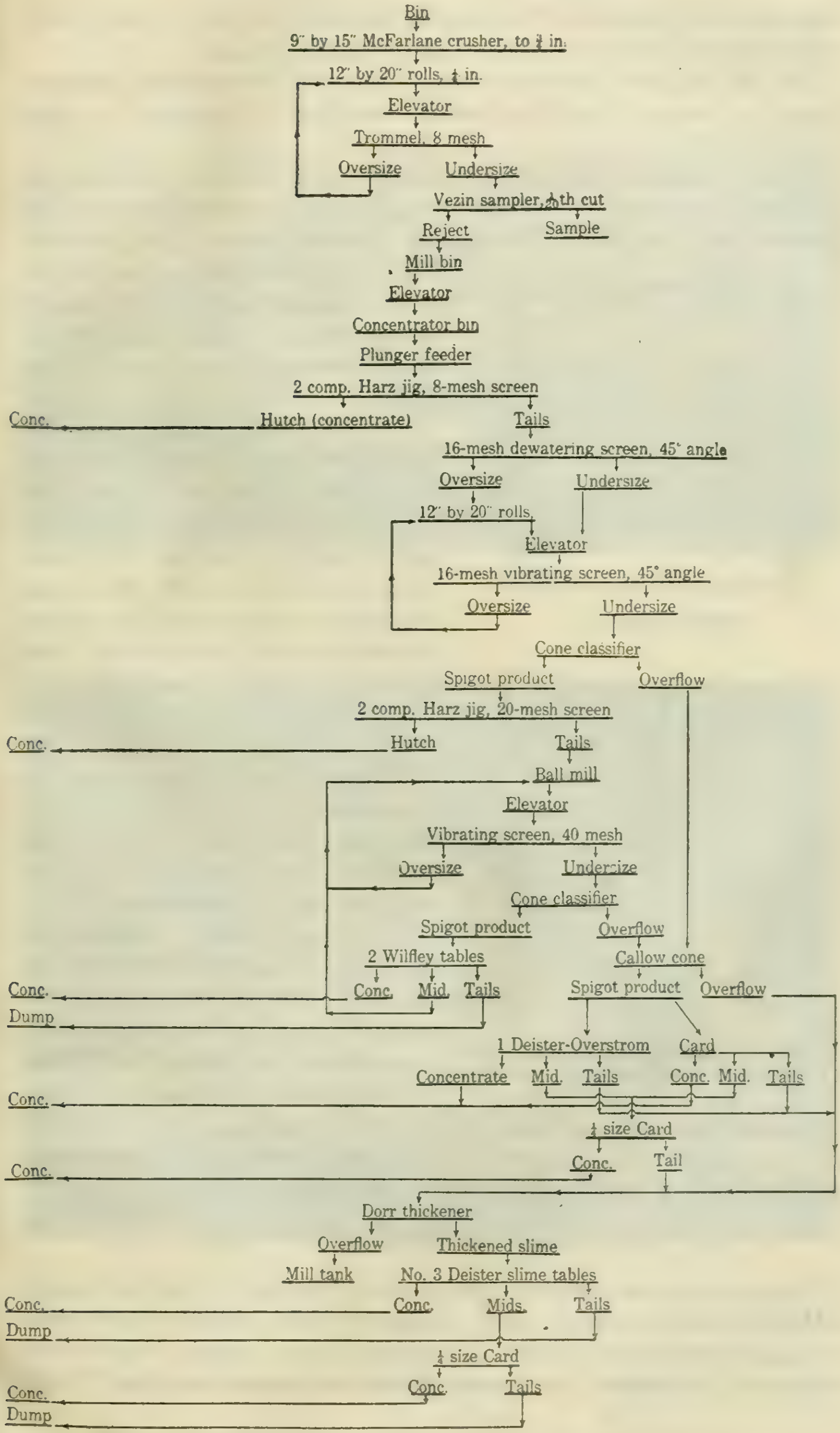


FIGURE 4.—Mill circuit of Tungsten Products Co. mill, Boulder, Colo.

keep the bed constant. On 8-mesh material the jig is run with a throw of $\frac{1}{4}$ to $\frac{5}{8}$ inch at a speed of 250 strokes a minute.

The jigs make 60 to 70 per cent of the total concentrate produced from the average ore, the product assaying 60 per cent or more tungstic oxide.

As the diagram shows, the undersize from the first 16-mesh dewatering screen passes to an elevator, joins the oversize that has been crushed, and goes with it to another 16-mesh screen. This peculiar flow is necessary on account of the mill arrangement. The screens are a modified type of the Colorado impact screen and are made in local shops.

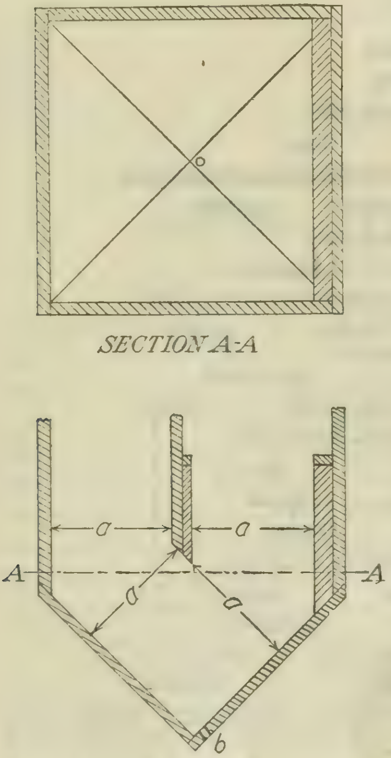


FIGURE 5.—Hartz jig in Tungsten Products Co. mill: *a*, dimensions; *b*, spigot.

The middling product from the Deister-Overstrom and Card tables is re-treated on a quarter-size Card table without crushing. This procedure makes a rather low-grade concentrate but avoids the losses incident to further crushing, as does the treatment of the middling from the Deister No. 3 slime table.

A dust collector is connected to the dry-crushing equipment.

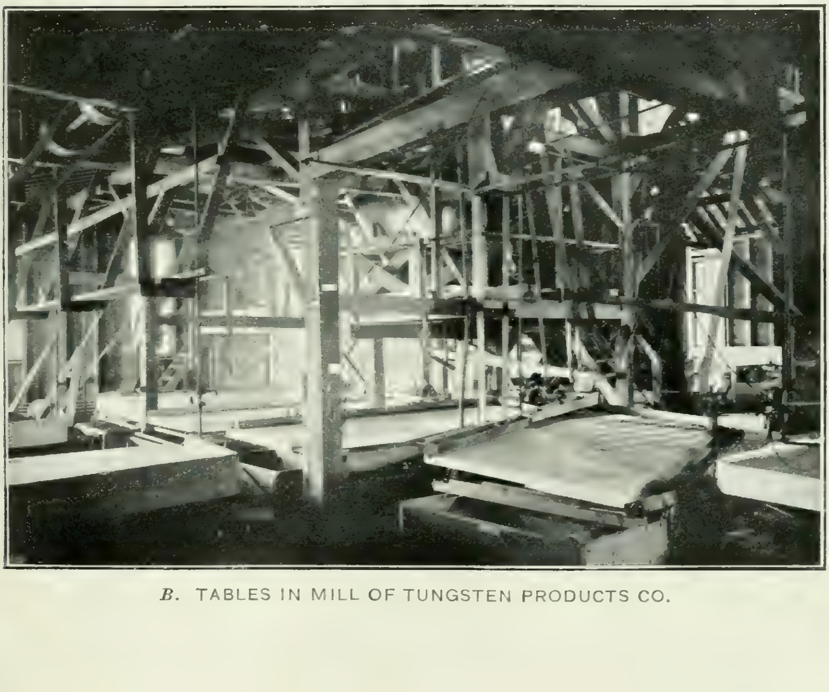
Different lots of crude ore may be retained in the mill bins until settlement for them is made, when they are transferred to the concentrator bin for treatment.

The high-grade concentrates from jigs, the tables, and the "slimers" are sent direct to the ferrotungsten plant. The second-grade concentrates are treated by Wetherill magnetic machines to remove impurities and to raise the grade. Plate IX, *A*, shows the exterior of the concentration mill of the Tungsten Products Co., and Plate IX, *B* (interior view), shows the concentrating tables.

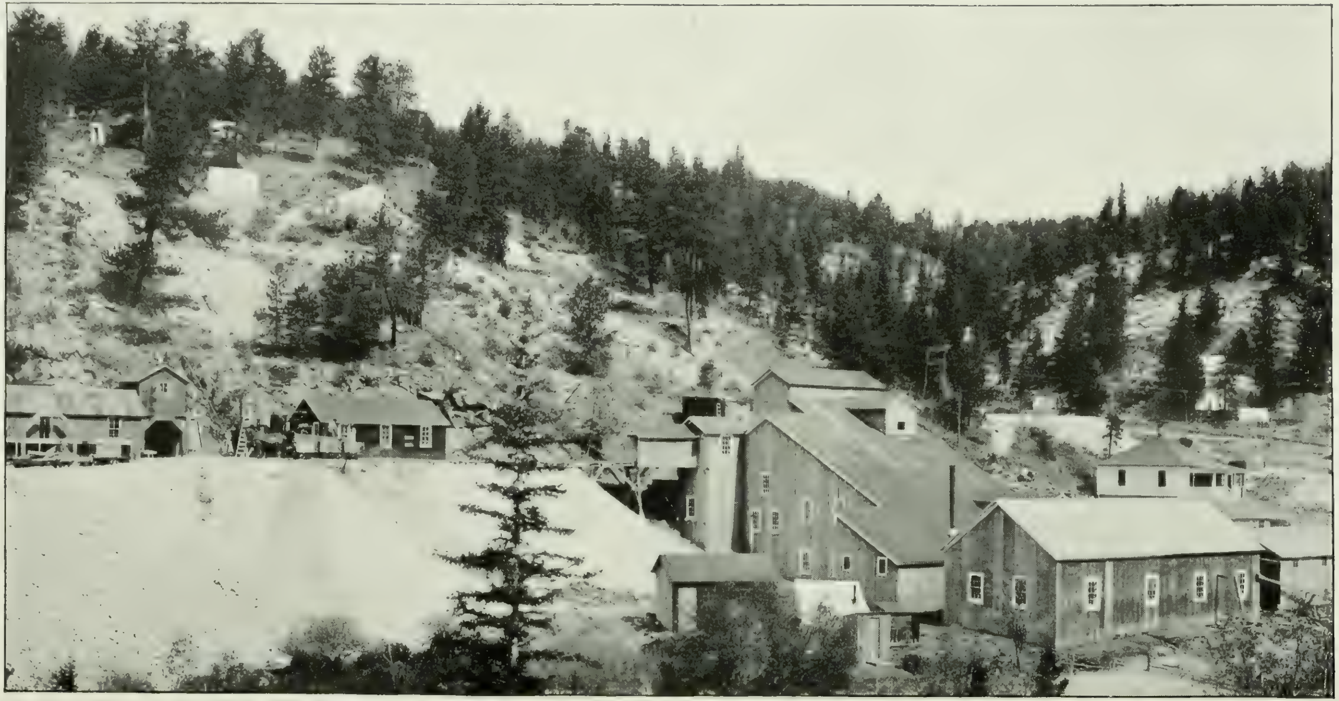
THE GRIMM CONCENTRATING MILL.

The Grimm concentrating mill is about 7 miles up Boulder Canyon (Middle Boulder Creek), near Ferberite, Colo., and is experimental in size, as only 1,000 pounds of material can be treated in one shift. The mill is operated by George Bland to demonstrate the "Bland

A. TUNGSTEN PRODUCTS MILL, TUNGSTEN, COLO.



B. TABLES IN MILL OF TUNGSTEN PRODUCTS CO.



MILL OF THE BOULDER TUNGSTEN PRODUCTION CO., TUNGSTEN. COLO.

screen," which was invented by his brother, John Bland. Claims made for this screen are that it will treat dry ball-milled tungsten ores and with some ores produces a direct concentrate, whereas with others the screened sized products will give better recoveries and cleaner concentrates when submitted to the tables than when classified by other means. The method of treatment practiced in 1919 was as follows:

Dry crushing in a ball mill, dry screening on the Bland screens of 40 and 60 meshes; the +40 material going to one Wilfley table, the −40 to +60 to another Wilfley table, and the −60 to Deister tables. In 1919 nothing was being done with the middling, tail, or slime. The middling and tail collected presumably will be dried and reground; the slime goes to waste.

The plant did not seem to be complete, at the time it was visited (January, 1919), as no jigs nor "rag plant" were installed.

The Bland screen has four superimposed screens, about 2 by 5 feet each, attached to a frame having four especially constructed legs of hickory wood. The whole frame is vibrated by a steel-tooth ratchet with 12 teeth that revolves about 300 times a minute, giving 3,600 impacts a minute to the frame and screens. Various sized China silk screens can be employed, with openings up to 0.0013 inch in diameter (corresponding to a hypothetical Tyler screen of 350 mesh), the object being to dry-size the material closely.[13]

In many of the concentrating plants in the district this screen had been installed, but later, on account of its small daily capacity, had been discarded, except in the Rare Metals Ore Co. mill at Rollinsville, Colo., which is described in connection with the treatment of the "rag plant" concentrates.

THE RED SIGN MILL.

The Red Sign mill is at Ferberite, about 7 miles up Boulder Canyon (Middle Boulder Creek) from Boulder, and is compact and well designed. Careful stage concentration is a feature, beginning with Richards pulsating jigs for material between 5 and 12 mesh in size. Bunker Hill screens of 30 and 50 mesh are used, and are said to be satisfactory. All tables make but two products—concentrates and tailings. Callow cones are used for thickening the slime table feed. The capacity of the mill is about 25 tons a day when treating 1 per cent ore. Cherty and rebellious hard silicates are treated. The flow sheet is similar in principle to those of other mills in the district but differs from that of the Tungsten Products Co. mill in that Richards jigs and Bunker Hill screens are used in preference to Harz jigs and impact screens. Treating 1 per cent ore the mill was making a saving of about 85 per cent. The concentrates are not all of 60 per cent grade, as some lower grade material can be shipped to the eastern refining plants for manufacture of tungstic acid and other products. The mill circuit is shown in figure 6.

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[13] Bland, George V., Dry sizing as a means of preparing feed for concentration: Eng. and Min. Jour., vol. 105, May 18, 1918, p. 908; Bland, John, Notes on screening: Eng. and Min. Jour., vol. 107, No. 26, June 28, 1919, p. 1112.

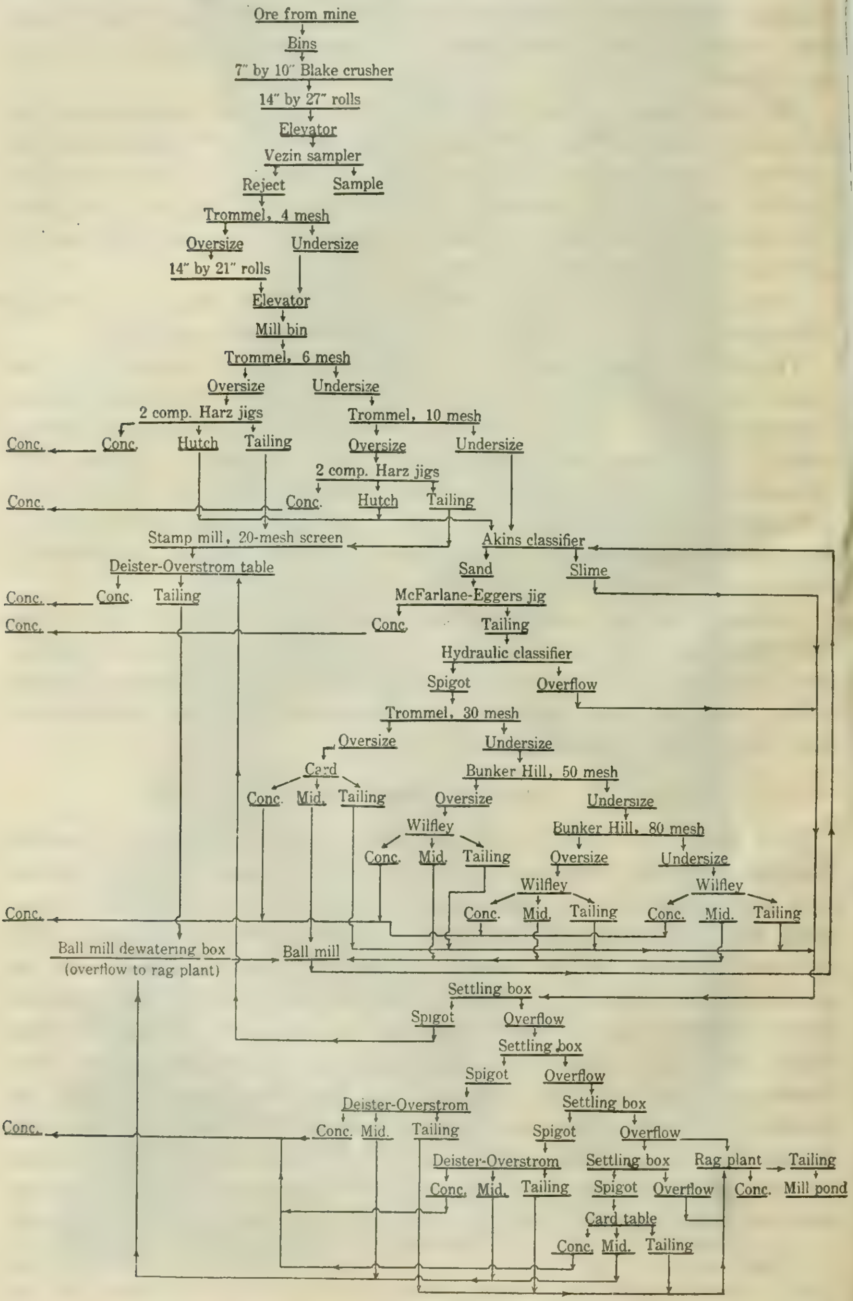
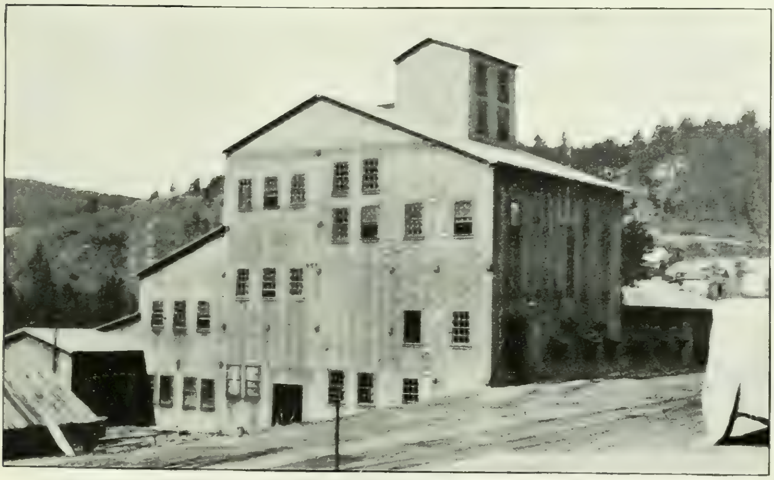
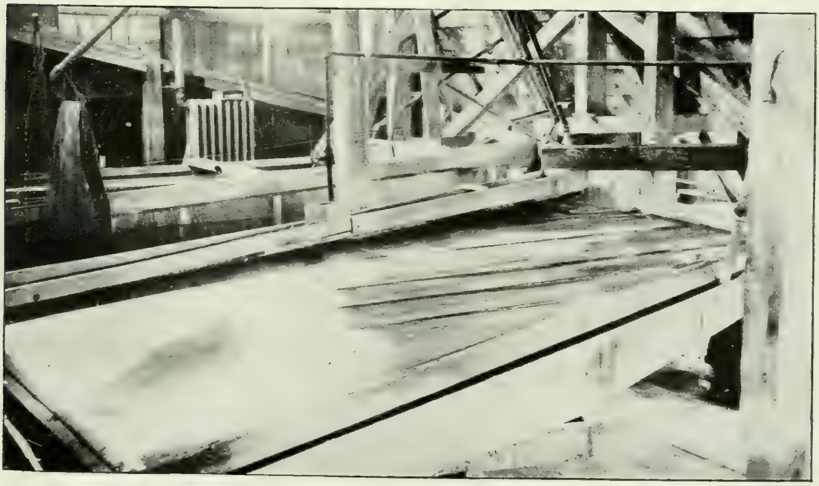


FIGURE 6.—Mill circuit of the Red Sign mill, Ferberite. Colo.

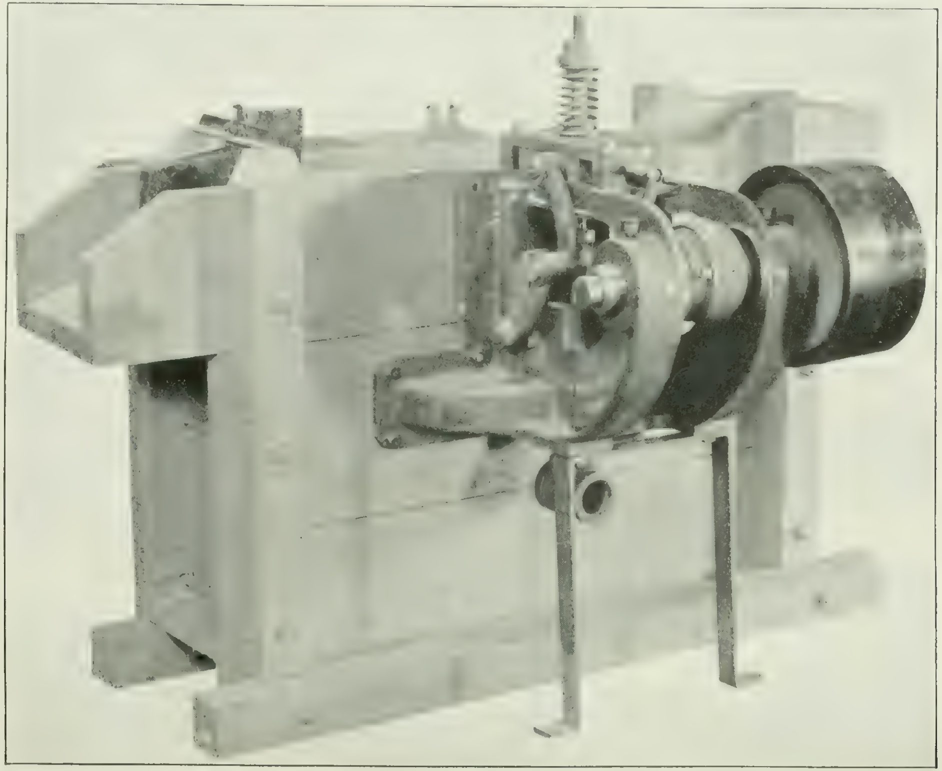
A. THE WOLF TONGUE MILL.



B. THE VASCO MILL.



C. DEISTER-OVERSTROM TABLE WITH WHITE ENAMELED DECK.



EGGERS DIFFERENTIAL PULSATING JIG IN USE AT THE WOLF TONGUE MILL.

THE VASCO MILL.

The Vasco mill, in Boulder Canyon (Middle Boulder Creek, about 14 miles from Boulder), at Tungsten, and owned by the Vanadium Alloy Steel Co., is one of the new mills of the district and is efficiently equipped. Recoveries, according to company officials, often exceed 90 per cent and occasionally 93 per cent, based on all grades of concentrates made. The mill was built to handle about 100 tons a day of 2 per cent ore, but the general average of ore in 1919 was between 2 and 10 per cent. A large part of the ore handled was coming from the company's mines, which are numbered from 1 to 13. One of the outstanding features of this mill is the absence of a "rag plant." All slimes are treated efficiently by employing many sets of slime tables. As in the other mills, attempts were made to produce as much 60 per cent concentrate as possible, but as the company has its own refineries, lower-grade concentrates can be utilized, down to 40 per cent. Thus the total recovery is increased, as the losses incident to raising the grade of concentrates are avoided. The mill circuit is shown in Plate XIII. Plate XI, *B*, shows an exterior view of the mill, and Plate XI, *C*, shows a view of a Deister-Overstrom table with a white enameled deck.

THE BOULDER TUNGSTEN PRODUCTION CO.

At Tungsten (Stevens Camp), Colo., also is the concentrating mill of the Boulder Tungsten Production Co. As the mill was closed at the time of the author's visit, it was not studied in detail. A mill circuit was, however, made and is shown in figure 7. An exterior view of the mill is shown by Plate X.

THE WOLF TONGUE MILL.

The Wolf Tongue mill at Nederland, on Middle Boulder Creek, at the head of Boulder Reservoir, 17 miles from Boulder, Colo., is one of the old stamp mills erected to treat gold and silver ores from the Caribou district and was later remodeled to handle tungsten ores. In 1919 it was the only tungsten mill in the district that used stamps; these had been discarded as primary crushers and were used for regrinding jig tailing. The capacity of the mill was 500 to 2,000 pounds of concentrate a day, depending upon the character of the ore. About 90 per cent of the ore handled was from the company's own mines, and of this amount about one-half was mined on company account and one-half by lessees. The mill circuit is shown in figure 8 and a view of the mill is given in Plate XI, *A*.

This mill has a new type of jig, the Eggers differential-stroke pulsating jig, which has efficiently treated tungsten ores. This jig is shown in Plate XII.

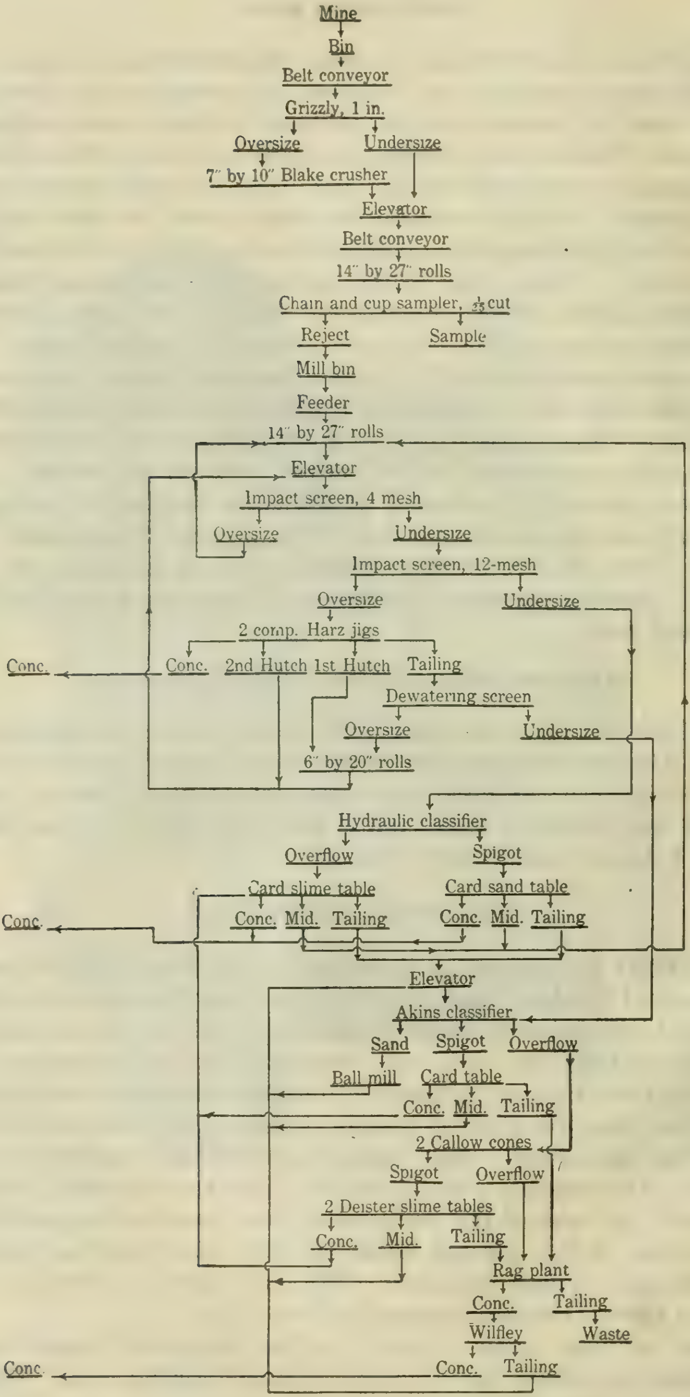
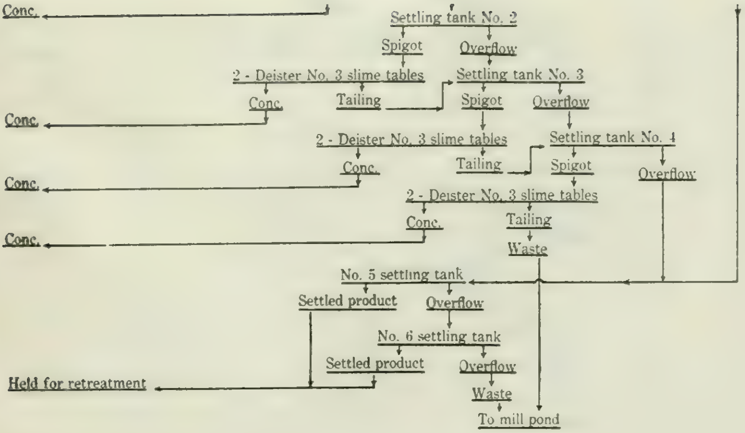
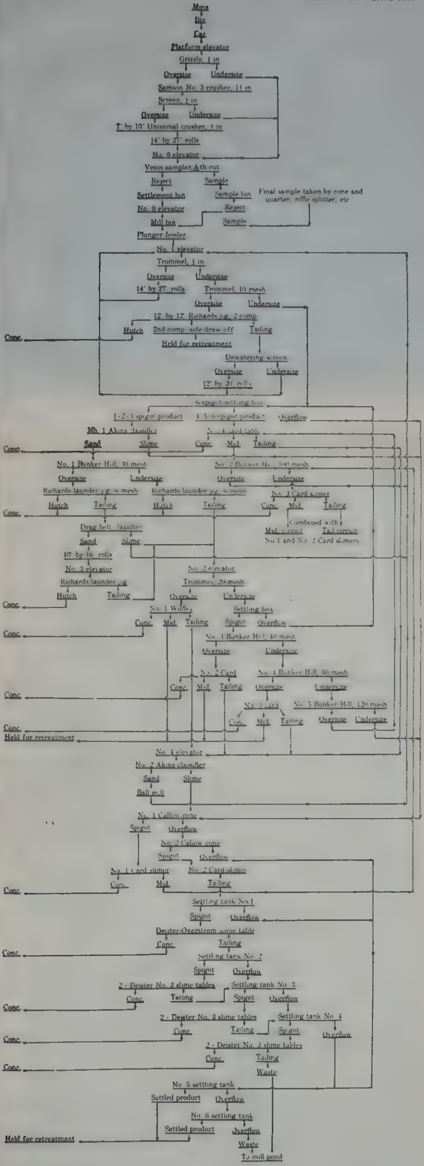


FIGURE 7.—Mill circuit of the Boulder Tungsten Production Co.'s mill, Tungsten, Colo.



THE VASCO MILL CIRCUIT.



THE VASCO MILL CIRCUIT.

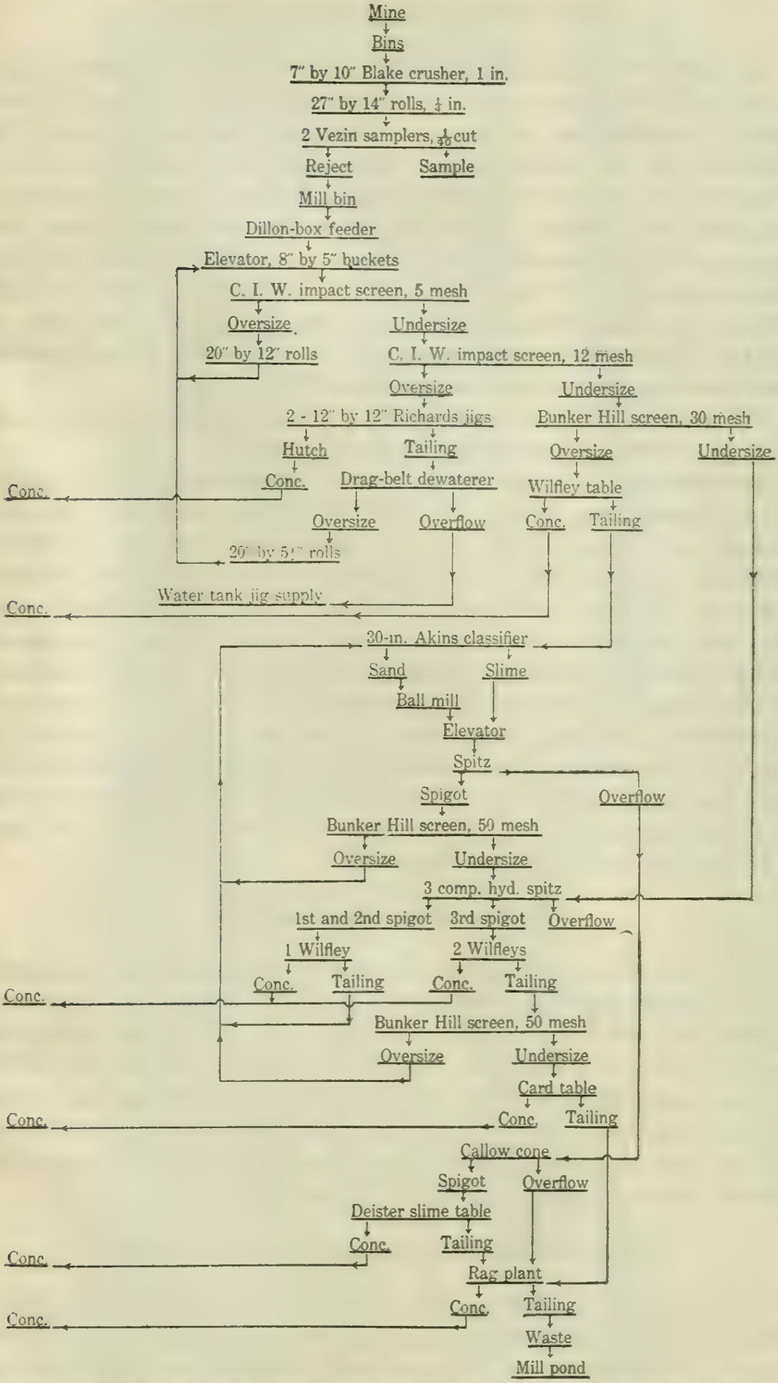


FIGURE 8.—Mill circuit of the Wolf Tongue Mining Co. mill, Nederland, Colo.

THE RARE METALS ORE CO. MILL.

The mill of the Rare Metals Ore Co., at Rollinsville, about 4 miles south of Nederland, on the Denver & Salt Lake Railroad (Moffat Road), was designed to treat ores from the company's mines in the northern end of Gilpin County, but it also handles custom ores. It is one of the new mills of the district and represents the latest in tungsten mill design. Excellent recoveries are made, even when treating the " horn-stone " ores. It has a capacity of about 50 tons of 1.5 per cent ore, or 25 tons of 4 or 5 per cent ore, or, in terms of units, from 75 to 125 units in 24 hours. Ores as low as 1 per cent are treated. Recoveries range from 80 to 90 per cent. All concentrates marketed contain 60 per cent or more WO_3.

The jig concentrate is obtained by skimming the bed at suitable intervals. The jig screens are 20 to 25 mesh.

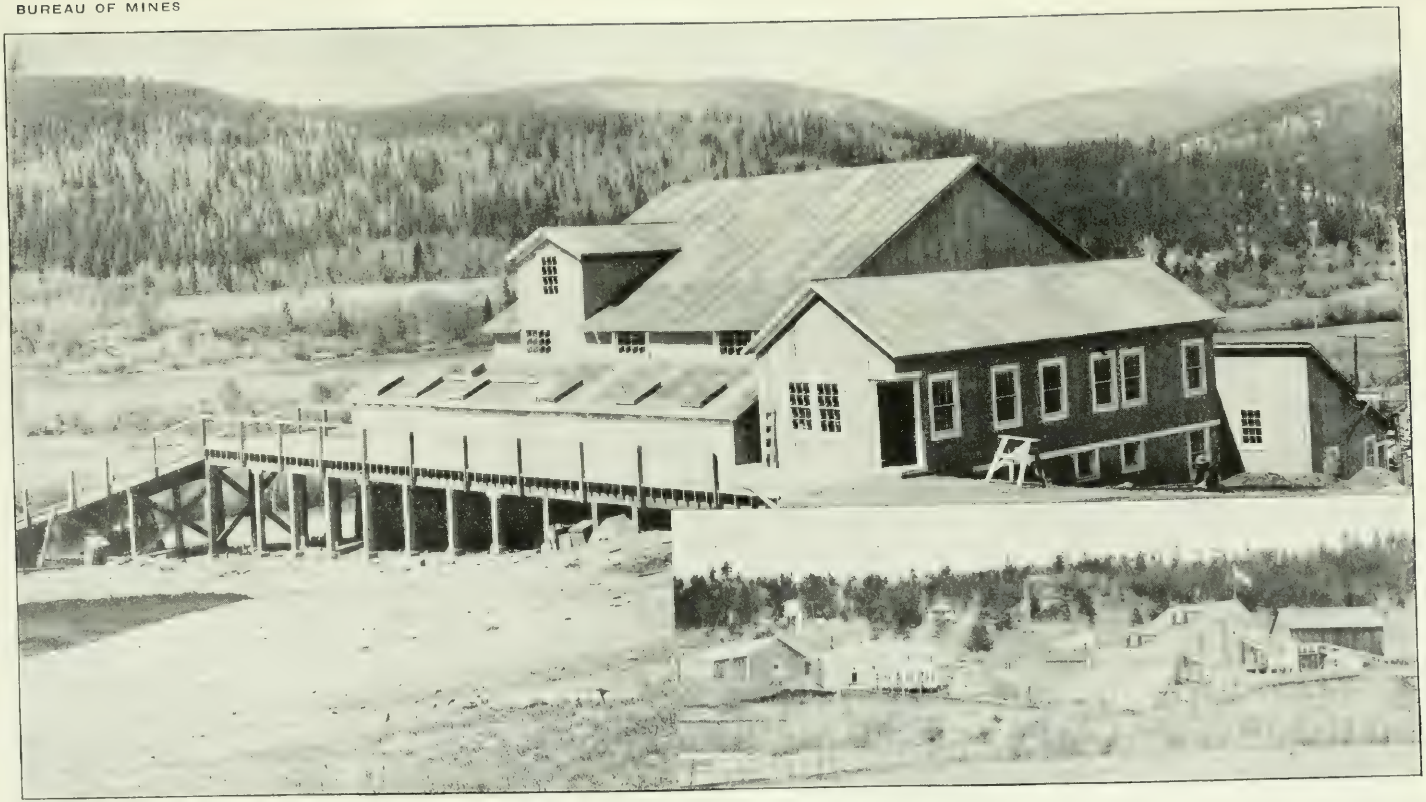
The treatment of the "rag plant" concentrates is of interest. These concentrates, which contain about 20 per cent WO_3, are dried and go to a Bland screen, which makes three products, as follows: Material retained on 0.004-inch opening, China silk cloth, which is put in the Wilfley table feed; material passing the 0.004-inch openings and retained on 0.002-inch openings, which is fed to a separate Deister table; and material passing through the 0.002-inch openings, which is high enough (40 or 50 per cent) in WO_3 to be mixed with concentrates carrying more than 60 per cent WO_3. This mill has concentrated scheelite ores, rebellious ore containing barite which was sent from the Orient for concentration, and also rejects from some of the other concentrating mills. The mill circuit is shown in figure 9, and a view of the mill in Plate XIV.

THE PRIMOS CHEMICAL CO.

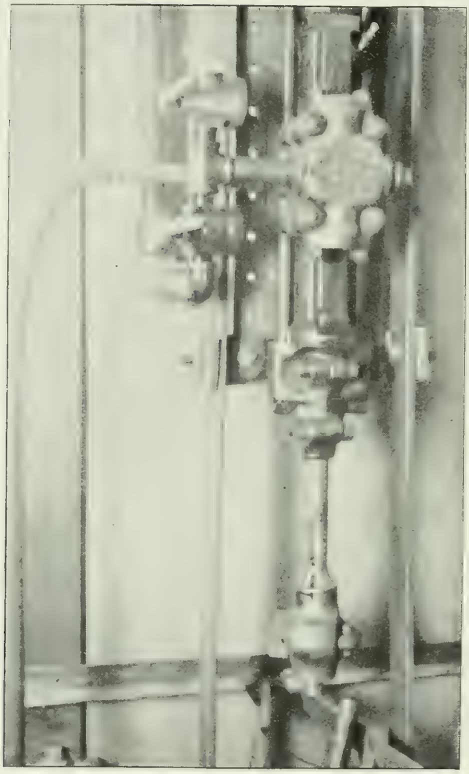
The Lakewood mill of the Primos Chemical Co., at Lakewood, Colo., 4 miles north of Nederland, formerly crushed all the ore by stamps and contained no jigs, tables and the "rag plant" being used entirely. In 1919, however, practice had been changed to conform to the better methods of the other mills. The mill handles custom ore and that from the company's own properties. An exterior view of the mill and the surrounding tract, showing the Conger and Beddig mines, appears in Plate III, *C* and *D* (p. 18).

MILL REPORT SHEETS AND CALCULATIONS.

Recovery is best calculated by comparing the number of pounds of WO_3 in the heads with the total number of pounds in the different concentrate products. All figures must be based on dry weight and accurate samples. Tailing samples, judged from the samples from



PLANT OF THE RARE METALS ORE CO., ROLLINSVILLE, COLO.



A. PISTON DRILL USED AS AN AIR HAMMER FOR PULVERIZING FERROTUNGSTEN IN A STEEL MORTAR.

B. CHEMICAL PLANT OF THE BLACK METAL REDUCTION CO.

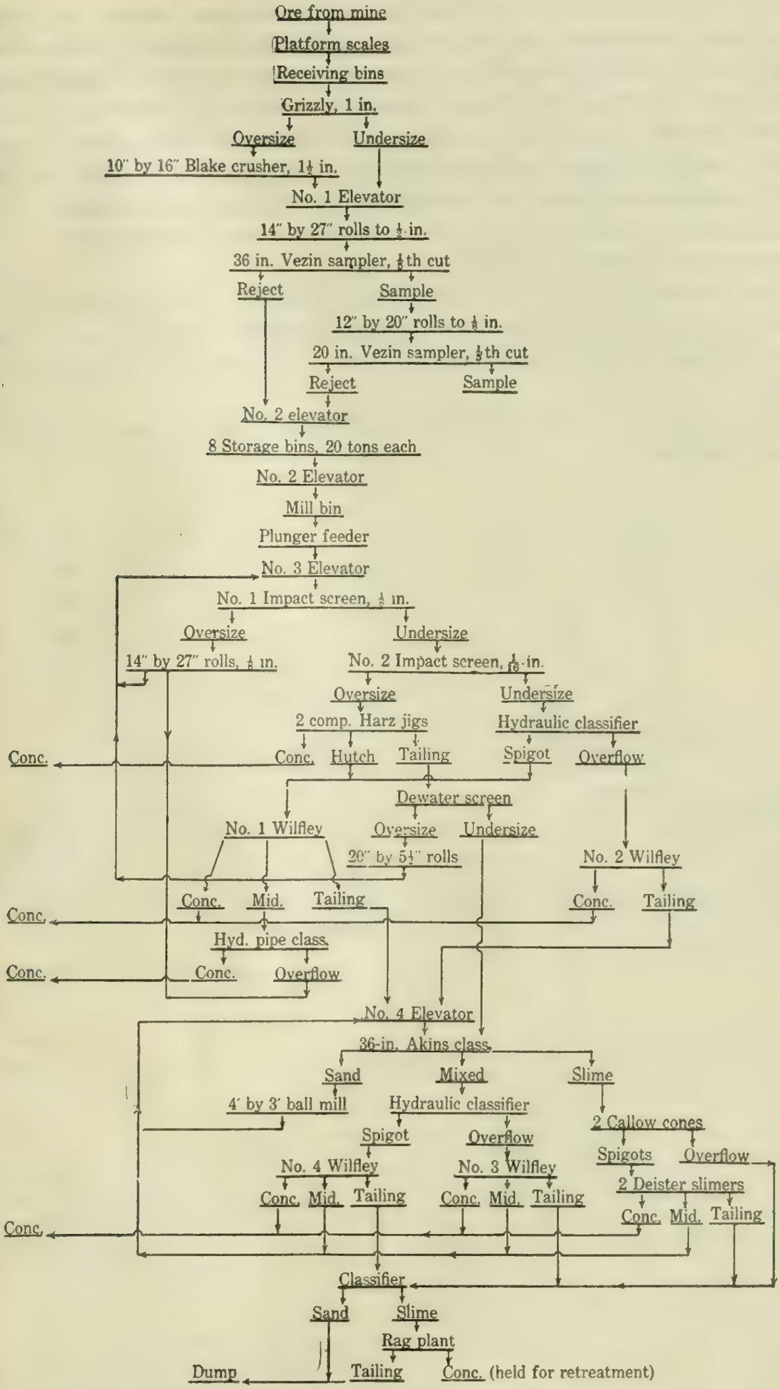


FIGURE 9.—Mill circuit of the Rare Metals Ore Co. mill, Rollinsville, Colo.

most of the mills in this district, give inaccurate results, as before the pulp passes over the rag plants, its last treatment, it is classified, the coarse going to waste and the slimes going to the canvas, thence to waste; and the two waste streams can not be combined so as to give accurate samples. In some mills where a "rag plant" is not used, settling boxes are installed for trap material which is held for retreatment later, this material may consist of thickened pulp from one or more lots, as it is not economically possible to keep each lot of such pulp separate.

At one mill—that of the Tungsten Products Co.—the mill flow is such as to give a very good tail sample, which is useful as a check. An automatic tailing sampler, as shown in figure 10, is used at this mill.

The typical mill sheet, shown in Table 6, shows how recoveries are calculated.

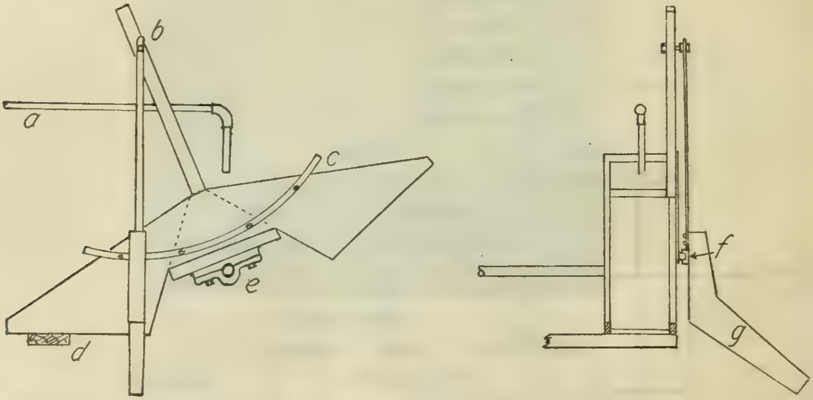


FIGURE 10.—Automatic tailing sampler: *a*, water; *b*, pivot; *c*, strap iron; *d*, stop; *e*, bearing; *f*, roller; *g*, cutter.

TABLE 6.—*A typical mill sheet.*

[Mill report run No. 56—Started Nov. 16: closed Dec. 29, 1918. Days' running time, 44, Boulder, Colo.]

Bill No.	Net weight.	Assay.	WO$_3$.	Gross value.	Remarks.
	Pounds.	*Percent.*	*Pounds.*		
1851	13, 323	9. 30	1, 239. 0	$712. 42	$18+15 per cent.
1852	7, 970	9. 70	773. 1	444. 53	Do.
1854	30, 144	12. 20	3, 677. 6	2, 114. 62	Do.
1855	2, 392	31. 50	753. 8	476. 77	Do.
1856	2, 688	21. 90	588. 7	338. 50	Do.
1857	1, 227	22. 10	271. 2	155. 94	Do.
1858	842	6. 20	52. 2	23. 28	Do.
1859	108	44. 40	48. 0	33. 12	Do.
1861	20, 247	11. 70	(?)2,368.9	1, 362. 11	Do.
1864	(?)277	19. 10	443. 4	25. 05	Do.
1865	40, 158	9. 65	3, 875. 2	2, 228. 24	Do.
1866	9, 638	3. 15	303. 6	87. 28	Do.
1867	824	7. 20	59. 3	34. 09	Do.
1868	10. 956	2. 55	279. 4	80. 32	Do.
1869	2, 351	6. 80	159. 9	86. 79	Do.
1873	13, 134	10. 00	1, 313. 4	755. 20	Do.
1874	921	11. 00	101. 3	58. 24	Do.
1876	6, 350	15. 00	952. 5	428. 62	$9 unit.[1]
1875	4, 156	. 85	35. 3	....	Do.
1872	5, 297	1. 05	55. 6	....	Do.
1877	4, 944	15. 90	786. 1	353. 74	Do.
1878	2, 203	33. 90	746. 8	336. 06	Do.
1879	16, 815	14. 30	2, 404. 5	1, 082. 02	Do.
1880	14, 716	15. 70	2, 310. 4	1, 039. 68	Do
	211. 632	10. 96	23, 199. 2	12, 256. 62	
Recovered	34, 592	59. 10	20, 442. 4	21, 157. 87	
Thrown away	177, 040	1. 56	2, 786. 8	....	

[1] Drop in price caused by the armistice.

CLASSIFICATION OF MILL ORES.

Under—	Net weight.	Assay.	WO$_3$.	Saving.	Low WO$_3$.	High WO$_3$.
	Pounds.	*Per cent.*	*Pounds.*	*Per cent.*	*Pounds.*	*Pounds.*
2 per cent	9, 453	0. 96	90. 9	40	18. 1	18. 2
2 to 5 per cent	20, 594	2. 83	583. 0	50	116. 6	174. 9
5 to 10 per cent	78, 692	9. 50	7, 472. 1	93	2, 241. 6	4, 707. 4
10 to 20 per cent	94, 364	13. 40	12, 644. 7	93	3, 793. 4	7, 966. 1
20 to 30 per cent	3, 915	21. 96	859. 9	94	171. 9	636. 3
30 to 40 per cent	4, 704	32. 92	1, 548. 6	96	309. 7	1, 176. 9
	211, 632	10. 96	23, 199. 2	91. 9	6, 651. 3	14, 679. 8

Computed from an "ultimate" table.

RECOVERED.

Bill No.	Kind.	Number of sacks.	Weight.	Assay.	WO$_3$.	Percentage WO$_3$ saved.	Value, $18 +15 per cent.
			Pounds.	*Per cent.*	*Pounds.*		
662	Jig	24	2, 280	57. 90	1, 320. 1	6. 5	$1, 366
663	do	22	2, 090	59. 60	1, 245. 6	6. 1	1, 289
664	Slimes	9	822	64. 10	526. 9	2. 5	545
665	Concentrates	9	883	59. 70	527. 2	2. 5	545
666	Jigs	109	10, 409	59. 30	6, 172. 5	30. 2	6, 388
668	Slimes	64	2, 966	60. 40	1, 791. 5	8. 8	1, 854
667	Jig	106	10, 072	57. 70	5, 811. 5	28. 4	6, 014
669	Concentrates	46	4, 529	60. 40	2, 735. 5	13. 4	2, 831
670	Slimes	6	541	57. 60	311. 6	1. 6	322
		......	34, 592	59. 10	20, 442. 4	100. 0	21, 157

294 hours on feed; 8 hours on repairs; 51 running sands and cleaning tanks.
88. 1 per cent, saving average 59.1 per cent grade.
71.2 per cent of recovery to jigs 57.6 per cent grade.
15.9 per cent of recovery to concentrates 60.3 per cent grade.
12.9 per cent of recovery to slimes, 60.7 per cent grade.

TREATMENT OF TUNGSTEN CONCENTRATES OF BOULDER COUNTY.

Information on tungsten, its uses, and its chemical and physical properties has appeared so often in various books on chemistry and in bulletins, technical papers, and the scientific press that these subjects will be dwelt upon only in brief and in connection with the description of the processes used for treating ferberite concentrates from the Boulder district. For detailed discussions of the chemistry of tungsten the reader is referred to the bibliography compiled by Hartmann.[14] The literature on the uses of tungsten metal, ferrotungsten, special alloys, and tungsten products is fairly complete, especially that published during the war, when tungsten steels and products were in such great demand.

Ferberite, found in Boulder County, Colo., is one of the most favorable forms of tungsten for the production of the ferrotungsten and tungstic oxide now being made at Boulder. As tungsten ores found in this district are practically free from cassiterite and contain only a very small percentage of injurious elements, such as arsenic and phosphorus, which are penalized in tungsten products, the manufacture of tungsten products from such ores has been highly successful in the Colorado plants.

USES OF TUNGSTEN.

The principal use of tungsten is the manufacture of high-speed tool steel, which, in addition to tungsten, contains chromium and vanadium. Contrary to a popular conception, no high-speed tool steel containing tungsten alone as an alloying element is produced. This misconception is due to the fact that these high-speed tool steels are usually spoken of as "tungsten steel." This use of tungsten in tool steel may be exemplified by comparison with ordinary high-grade carbon steel. Under the standard adopted for testing tool steels the ordinary carbon steel failed at a speed of 15 feet a minute, whereas a tungsten-steel tool withstood 90 feet a minute and its edge became dull red in diffused daylight.

Tungsten gives to steel both hardness and the property of holding its temper under a high temperature. For alloying steel both tungsten metal and ferrotungsten are used. The commercial ferrotungsten from the electric furnace contains 50 to 85 per cent tungsten and 0.5 to 0.4 per cent carbon. The average quantity of tungsten used in permanent-magnet steel is 6 per cent, and in high-speed tool steels 18 per cent.

For introducing tungsten into steel, tungsten powder made by the reduction of pure tungstic acid (WO_3) by hydrogen, carbon monoxide, or other reducing gases was formerly used to the exclusion of other tungsten compounds, but has largely been replaced by ferrotungsten, which is claimed to lose less metal by oxidation and to produce a more uniform solution of tungsten in the steel. Over 90 per cent of the tungsten manufactured is used in steel making.

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[14] Runner, J. J., and Hartmann, M. L., The occurrence, chemistry, metallurgy, and uses of tungsten, including a bibliography of tungsten: South Dakota School of Mines Bull. 12, 1918.

Tungsten alloys are used or have been suggested for many purposes, as tungsten can be alloyed with most metals. It alloys readily with nickel, cobalt, molybdenum, uranium, chromium, iron, manganese, vanadium, and titanium.

Native tungsten has never been found, but under proper heating and working conditions manufactured tungsten metal becomes ductile and can be drawn into ribbons and fine wire. It is used in such form for high-temperature furnaces operating in an inert atmosphere. The saving which has resulted from its use in tungsten-filament lamps amounts to millions of dollars a year.

Some other uses of tungsten are replacing platinum and platinum-iridium alloys for contact points in spark coils, voltage regulators, telegraph instruments, and other electrical devices; wrought tungsten targets for X-ray tubes; finely divided tungsten as catalytic agent in the production of ammonia from nitrogen and hydrogen; permanent magnets made by heating and quenching a steel containing 4 to 5 per cent of tungsten and 0.5 to 0.7 per cent of carbon; and in parts for gas engines, such as valves.

The chemistry of tungsten is well described by Thorpe [15] and also by Runner and Hartmann.[16]

MANUFACTURE OF TUNGSTIC POWDER.

Before the writers visited the district several thousand pounds of tungstic powder had been produced by the Tungsten Products Co. directly from its own tungstic oxide. During the war the demand for ferrotungsten was so great that the manufacture of tungstic powder was discontinued, therefore details of operation were not obtained. The powder produced averaged from 96 to 98 per cent tungsten, 0.25 per cent carbon, below 0.02 per cent sulphur, a trace of phosphorus, and a small percentage of silica.

TUNGSTIC ACID MADE IN COLORADO.

During 1917 and part of 1918 two companies were manufacturing tungstic acid in Colorado. These were the Tungsten Products Co. and the Black Metal Reduction Co., both at Boulder. The Tungsten Products Co. had produced over 50 tons of tungstic acid, averaging around 99.5 per cent WO_3 and containing only a small percentage of phosphorus and sulphur. At the time of the writers' visit (January, 1919) only the plant of the Black Metal Reduction Co. was running.

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[15] Thorpe, Edward. A Dictionary of Applied Chemistry, vol. 5, 1913, p. 562.

[16] Work cited.

PLANT OF THE BLACK METAL REDUCTION CO.

The mill of the Black Metal Reduction Co. (Pl. XV, *B*) treats tungsten ores containing as low as 12 per cent WO_3 and produces a high-grade tungstic acid (WO_3), said to contain less than 0.03 per cent phosphorus, 0.3 per cent sulphur, and only a small percentage of silica. After drying, its purity ranges from 99 to 99.7 per cent WO_3. The production in 1919 was about 500 pounds of tungstic acid a day, which would correspond to treating 3,000 pounds of ore of about 20 per cent grade. The process is claimed to treat economically ore containing less than 12 per cent, but higher-grade ore is sought. The ore is bought from custom mills and from miners. A description of the process follows:

The ore is mixed with sodium carbonate and salt, and the charge is placed for about an hour in sheet-iron pans measuring 2 by 4 feet and 6 inches in depth, in a fire-brick furnace heated by a Case crude-oil burner. The charge is so proportioned that a glass slag is obtained. The pans are pulled out of the furnace onto an iron rack, are clamped and inverted, and the fused charge is dumped into an iron receptacle, where it cools. The charge is broken into pieces and ground by a jaw crusher to approximately one-half inch size. The crushed material is stored in a bin from which a weighed amount is charged into a large cement mixer and treated with hot-water wash liquor from a previous run.

After lixiviation the contents of the cement mixer are dumped into a screen-bottom trough, which retains the coarse residue. This residue is shoveled back into the cement mixer and washed with hot water, and this hot-water wash liquor is retained and used for the original wash in the next run. The concentrated solution which passes the screen trough goes into a sump, from which it is pumped into a desliming, baffle tank, and from there is run into another tank, where a further settling takes place. The clear solution from this tank is pumped to the top of the building to a so-called "special treatment tank." .The treatment given in this tank, said to be the only secret connected with the process, removes the last traces of phosphorus, arsenic, silica, and other deleterious substances. The contents of this tank are put through a Sweetland filter press, from which the clear solution is run into a large wooden tank, heated by steam coils, in which calcium tungstate is precipitated by the addition of a solution of calcium chloride.

The precipitate is allowed to settle, scraped out and dumped into a wooden revolving drum, where it is treated with commercial hydrochloric acid. It is then allowed to settle and the solution is drawn off through a suction filter. The residue is treated twice in this manner with hydrochloric acid, and finally the whole is dumped onto the suction filters. The precipitate is tungstic acid. The acid solution, which contains the calcium chloride and calcium sulphate, is allowed to run into stone vessels, where the calcium sulphate finally crystallizes out. The clear acid solution is then drawn into barrels, lime is added, producing calcium chloride, which is allowed to settle. The residue obtained in these barrels usually contains 15 to 20 per cent tungstic oxide. This calcium chloride solution is used for further precipitations. The tungstic acid is placed in wooden pans, dried in a steam-piped oven and shipped in sheet-iron drums. The moisture content of this acid is 5 to 10 per cent. The process is covered by United States Patent 1255144, February 5, 1918.

MANUFACTURE OF FERROTUNGSTEN.

Three electric smelting plants have been built in Colorado to smelt ferberite concentrates, as listed in Table 7:[17]

TABLE 7.—*Colorado ferrotungsten plants.*

Company.	Location.	Capacity, kilowatts.	Product.
Tungsten Products Co.	Boulder	800	Ferrotungsten.
Boulder Tungsten Production Co.	do	400	Do.
Ferro-Alloy Co	Utah Junction	2,700	300 kilowatts formerly used for making ferrotungsten; later all used for making ferrochrome.

TUNGSTEN PRODUCTS CO.

The plant of the Tungsten Products Co. is on the north bank of Boulder Creek, in the mouth of the canyon and on the outskirts of the city of Boulder. Power is supplied to the plant by the Colorado Power Co. at a nominal voltage of 13,200 volts. It is metered by the power company at a point outside the city limits of Boulder and is conducted to the reduction plant over the private line of the Tungsten Products Co., where the furnace transformers of the company transform it to a furnace voltage of from 55 to 90 volts. The furnaces are installed in a wooden frame building with corrugated-iron siding and roofing, but the transformers are in a fireproof substation.

Ferberite concentrate, other domestic ores, and imported scheelite and wolframite are smelted at this plant. Much of the concentrate is purchased in a low-grade form or contains impurities. Before smelting, this material is treated on a Wetherill magnetic separator to raise the grade and remove the impurities. Other raw materials are lime, silica, and coke.

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[17] Keeney, Robert M., The manufacture of ferro-alloys in the electric furnace: Bull. American Institute of Min. and Met. Eng., August, 1918, p. 1321.

The furnaces range in size from 75 to 150 kw. and have been operated at voltages ranging from 55 to 90 volts, but were finally operated at a voltage of 55 to 65 volts, as with the lower voltages metal could be produced containing less slag. The furnaces have a vertical, movable carbon or graphite electrode, a bottom contact of carbon embedded in the floor and a knockdown steel shell, lined usually with coke rammed in place with hot pitch as a binder. The so-called acid process is used, and the coke lining is used except when refining with a basic slag to remove impurities is necessary; then a magnesite lining is used. The shells of the larger furnaces are about 4 feet 6 inches in diameter by 4 feet 6 inches deep, are set on a fire-brick base, and have a turtleback roof with one end open for charging. There is a single tap hole for removal of slag as it rises in the furnace, all metal collecting in a button in the furnace bottom. The vertical electrodes are either of graphite, 4 inches in diameter, or of carbon, 6 inches in diameter, and are suspended by steel cables with automatic control of the electrodes and the load on the furnaces by Thury electrode regulators and electric winches. Plate XVI, *B*, shows the exterior of the smelter and chemical plant, and Plates XVI, *A*, and XVII show the electric furnaces in operation.

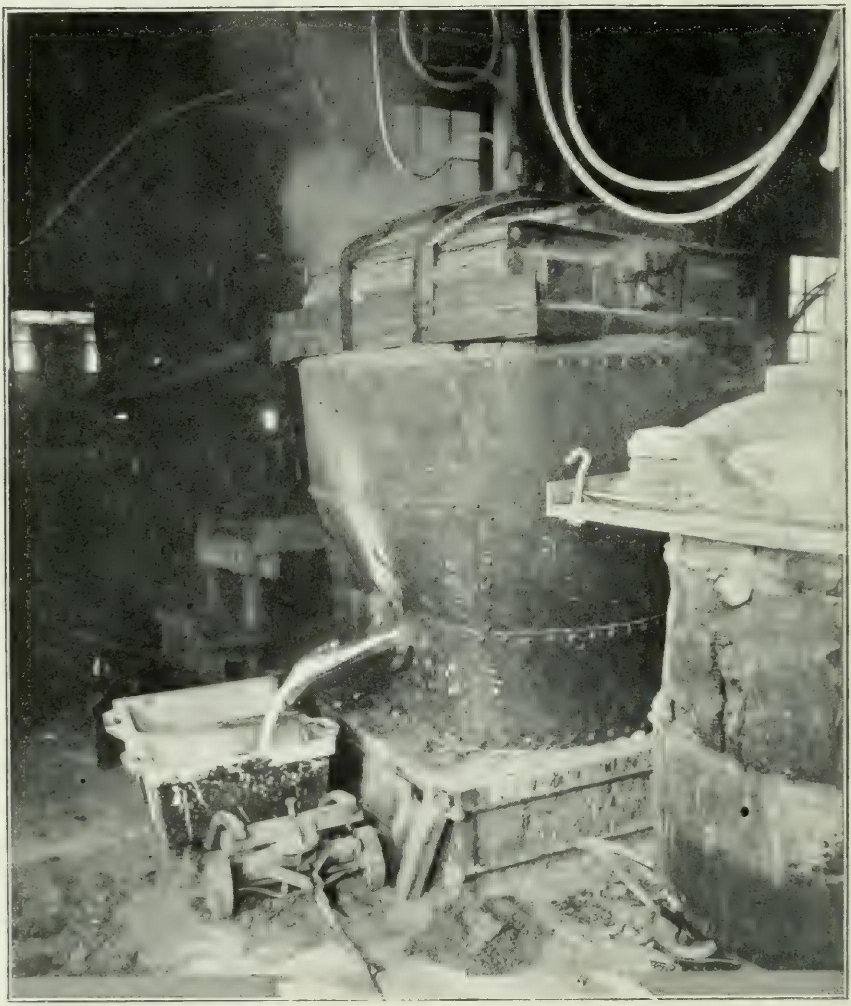
A general outline of the process follows:

The empty furnace shell, with a form in it, is set on the floor and rammed from bottom to top with coke and hot pitch. There is no bottom to the shell. When the lining has set, the shell is lifted with chain blocks and placed on the fire-brick base surrounding the bottom carbon contact. A fire-brick base is placed on the furnace, leaving one end open for charging. The electrode is lowered into place, contact through the bottom is obtained by hand control of the electrode, and charging is started by shoveling the mixture through the side roof opening at regular intervals. As soon as a bath of slag forms on the bottom the electrodes are operated automatically by the Thury regulators.

The ferrotungsten forms a pasty button about 2 feet in diameter on the lower contact and gradually builds up, raising the slag level until the latter is above the tap hole, when the slag is tapped. This continues for about 72 hours. The slag is tapped at regular intervals until the furnace contains 2,000 to 5,000 pounds of ferrotungsten, then the roof is removed, and the shell containing the metal and lining is lifted to the base. After cooling a little the lining and metal are removed from the shell. The metal button is cleaned with pneumatic cleaning tools and placed under a skull cracker of the usual steel-works type which breaks the ferrotungsten into 75 to 100

A. FERROTUNGSTEN FURNACES IN OPERATION.

B. SMELTER AND CHEMICAL PLANT OF TUNGSTEN PRODUCTS CO.



ONE OF THE LARGE ELECTRIC FURNACES OF THE TUNGSTEN PRODUCTS CO.

pound chunks. These chunks are broken to fist size under a steam hammer and crushed further in a jaw crusher and rolls to pass ¼-inch mesh.

In brief, ferrotungsten is produced at this plant in a single operation by smelting with an acid slag in an electric furnace with a carbon lining. Because of the metal being pasty as it forms in the furnace, carbon is not absorbed from the lining, and the acid slag prevents absorption from the reducing carbon in the charge. With a high phosphorus ore, however, basic refining is sometimes necessary to remove the phosphorus in the metal first reduced. As far as can be judged, the grade of product made is one of the highest produced in this country, as it averages 80 to 85 per cent tungsten, less than 0.5 per cent carbon, less than 0.03 per cent phosphorus, and less than 0.03 per cent sulphur, with about 0.5 per cent manganese and silicon. The plant has a capacity of 4,000 pounds of contained tungsten in 24 hours.

BOULDER TUNGSTEN PRODUCTION CO.

The plant of the Boulder Tungsten Production Co. is on the south bank of Boulder Creek and in the mouth of the canyon, just outside the city limits of Boulder. Power is supplied to the plant by the Colorado Power Co. at a nominal voltage of 13,200 volts and is transformed to a furnace voltage of from 50 to 100 volts by two 200 kva. furnace transformers, connected by the Scott connection. The furnaces are in a frame building.

The ore smelted was ferberite concentrate from the company's mine and mill. The plant ran only a few weeks, producing several thousand pounds of ferrotungsten of variable grade.

Four small pot furnaces of the general type described above carried a load of 75 to 100 kw. The shells were about 3 feet in diameter and 3 feet deep. The electrodes, of 4-inch graphite or 5-inch carbon, were regulated by hand-operated winches. As there was only one primary switch for the four furnaces control of a furnace was difficult. Small buttons of ferrotungsten, weighing about 500 pounds, were produced. Details of the process used were not available. This plant also includes a tungstic acid plant, which on account of the high cost of production, had been temporarily discontinued.

FERRO-ALLOY CO.

Keeney[18] has given the following description of the furnaces of the Ferro-Alloy Co.:

> The plant of the Ferro-Alloy Co., at Utah Junction, contains one 750-kw. three-phase furnace, to which power is supplied by three 250-kw. transformers,

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[18] Keeney, R. M., Work cited.

connected so as to give 129 volts on the furnace cables, the transformer ratio being 13,200 to 75 volts. The furnace operates with an actual voltage of 120 volts and produces about 3 tons of ferrochrome per 24 hours from 40 per cent Cr_2O_3 ore. The furnace consists of a steel shell of circular cross section, 8 feet (2.43 m.) in diameter by 7 feet (2.13 m.) deep, lined with magnesite, and having three vertical carbon electrodes 12 inches (30.48 cm.) in diameter.

A 450-kw. furnace, of the same size as the 750-kw. furnace, is also operated on chrome ore. This furnace is three-phase in appearance but operates electrically as a single-phase furnace. There are three vertical carbon electrodes 8 inches (20.32 cm.) in diameter with a conducting carbon bottom. Power is supplied by three 150-kw., single-phase transformers, two of which have a ratio of 13,200 to 95 volts and one a ratio of 13,200 to 100 volts. From each transformer one lead goes to one vertical electrode, and one lead to the carbon bottom, so that the transformers are electrically independent. The furnace voltage varies from 90 to 95 volts.

At intervals, 150-kw., single-phase furnaces are operated on ferrotungsten. These furnaces have one vertical graphite electrode 4 inches (10.16 cm.) in diameter, with a water-cooled steel bottom contact. The furnace shells are 4 feet (1.22 m.) in diameter and are mounted on trunnions, the slag being poured by tilting the furnace. All of the electrodes are regulated by hand. The chrome furnaces are operated without roofs and the tungsten furnaces with roofs. The whole plant has a power factor of 90 per cent.

The following description of the manufacture of ferrotungsten in Colorado has been given by Keeney:[19]

Tungsten is the leading alloy metal used in the manufacture of high-speed steel. Probably about half of the consumption is used in the form of ferrotungsten, the remainder being tungsten metal. Colorado has supplied a large part of the tungsten used in steel manufacture, but is gradually being surpassed by California, where the large scheelite deposits can produce tungsten considerably cheaper. Ferberite, found in Boulder County, Colo., is one of the most favorable forms of tungsten for production of ferrotungsten, containing both iron and tungsten in the proper proportion to yield 70 to 80 per cent ferrotungsten. At present, three electric-furnace plants in Colorado are making or have made ferrotungsten. The standard grade produced by the Ferro-Alloy Co. contains 75 per cent tungsten, 0.8 per cent carbon, 0.4 per cent silicon, 0.5 per cent manganese, 0.01 sulphur, and 0.02 per cent phosphorus. The Tungsten Products Co. makes about the same grade of product, except that the carbon is kept below 0.5 per cent and the tungsten runs as high as 85 per cent. The product of this company is probably the highest grade and the purest ferrotungsten made in this country. Ferrotungsten has a high density, fine gray fracture, and is not crystalline—the higher the carbon the coarser the fracture. The carbon in ferrotungsten occurs as the double carbide, $Fe_2C.W_2C$.

One method commonly employed for production of ferrotungsten is reduction of ferberite or some other concentrate in the electric furnace, with carbon as a reducing agent, followed by a subsequent refining and decarburization. Reduction with carbon takes place according to the following reaction:

$$FeWO_4+4C=FeW+4CO.$$

Theoretically the product would contain 76.6 per cent tungsten. The slag may contain as high as 8 per cent FeO, but less than 1 per cent WO_3. Theoretically the reduction of 100 parts of alloy from 126 parts of ferberite requires 20 parts of carbon, but practically about 25 per cent excess of carbon is charged. Small amounts of lime and fluorspar are used to flux the silica. Operating in this manner with an excess of carbon a product is made containing 3 per cent carbon, 70 per cent tungsten, 0.05 per cent phosphorus, and 0.01 per cent sulphur; the slag contains below 1 per cent WO_3. If desired, this product can be tapped from the furnace, but as its behavior is erratic, it is preferable to allow the metal to collect in the bottom of the furnace, forming, in a 150-kw. furnace a button about 3 feet in diameter, 6 inches thick, and weighing 1,000 to 1,200 pounds; the slag is poured off by tilting as it fills the furnace.

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[19] Keeney, R. M., The manufacture of ferroalloys in Colorado: Eng. and Min. Jour., vol. 106, No. 9, Aug. 31, 1918, p. 405.

Smelting of ferberite concentrate.—A typical operation is conducted as follows: The initial charge is 65 pounds of a mixture composed of 200 pounds concentrate, 42 pounds coke, 56 pounds lime, 6 pounds fluorspar. Three more 65-pound charges are added at intervals of half an hour, and at 2½ hours from the start the furnace is tilted and the slag poured. This cycle is repeated until a 1,200-pound button has been formed, requiring 24 to 36 hours. The furnace is allowed to cool, is torn down, and the button of metal removed. This is then cleaned and broken up, the breaking process being somewhat difficult with a 3 per cent carbon alloy.

The slags produced average 0.72 per cent tungsten, and though there is considerable mechanical loss, due principally to dusting, the total loss in practice does not exceed 5 per cent.

Refining ferrotungsten.—The crude metal, broken to about 6-inch size, is refined as follows: A charge of 150-pound metal and 75-pound ferberite concentrate is smelted for half an hour, when 12 pounds of fluorspar is added. After another 3 hours the slag is poured, and a fresh charge is started. The process is continued for from 36 to 48 hours, until a button weighing 1,500 pounds has formed in the furnace, a larger button being permissible because the low-carbon alloy is easier to break. The furnace is allowed to cool, is torn down, and the button of metal removed, cleaned, and broken. The refined button forms compactly and is free from slag. The refining reduces the carbon from 3 to 0.8 per cent, the phosphorous from 0.05 to 0.01 per cent, leaves the sulphur the same, and increases the tungsten from 70 to 75 per cent. The refining slag contains 5 to 20 per cent tungsten, and is resmelted in a special run.

Ferrotungsten is one of the easiest ferroalloys to manufacture, except for the fact that it must be made in a knockdown furnace, due to the high melting point of the alloy, about 2,500° C. Metallurgically it is simple, as tungsten has not so great a tendency to form carbides or to oxidize as have chromium and uranium. Ferrotungsten containing less than 1 per cent carbon can be made in a single smelting operation by careful regulation of the carbon in the charge and the use of an acid slag. The disadvantage of this method is that the product is less pure, and the slag loss is considerably higher. The metal will contain much higher phosphorus and sulphur, and the total loss of tungsten may be 25 per cent, as compared with 10 to 15 per cent by the two-stage process.

Nearly every manufacturer of ferrotungsten has tried to tap it from the furnace, but none has continued the practice. If the tungsten is reduced to 55 to 60 per cent, the alloy can be tapped, even with carbon as low as 0.2 per cent. With tungsten at 70 per cent, metal containing 0.9 per cent carbon has run out while pouring slag, but generally any metal which comes out with the slag will contain 1.25 per cent carbon. The irregularity of tapping operations with ferrotungsten has prevented the adoption of that method, because if part of the metal must be retained in the furnace, it is cheaper to keep it all there. Furthermore, the poured metal is very hard to break.

In ferrotungsten production it is essential to maintain regularity of charging, as this is the only way to insure homogeneous composition of the metal, as the button is not melted throughout. Even during refining, the metal does not melt to any extent, the action taking place while the metal is in a pasty condition. To insure a more homogeneous product, consumers require the alloy to be crushed to one-fourth inch, this crushing forming one of the main trials of the manufacturer.

Ferrotungsten analyses.

	Per cent.
Tungsten	69.7 –74.19
Carbon	.88 – 1.00
Silicon	.39 – .76
Manganese	.15 – .53
Sulphur	.002– .055
Phosphorus	.013– .037

Analyses of ferrotungsten made from ferberite by smelting and refining indicate the limits in composition shown in the table.

IMPURITIES IN FERROTUNGSTEN MANUFACTURE.

The most objectionable impurities in concentrates used for the manufacture of ferrotungsten are phosphorus, copper, tin, and sulphur. Of these impurities the only one that ferberite concentrate is likely to contain to an injurious degree is phosphorus. Some phosphorus may be removed by magnetic concentration, or from crude ferrotungsten, by basic refining. The general guarantee made by ferrotungsten manufacturers is that the phosphorus in the ferrotungsten will not exceed the percentage of phosphorus in the concentrate smelted. Guarantees made by the two companies named below were as follows:

Quality of ferrotungsten as guaranteed.

	Vanadium Alloy Steel Co.	Ferro-Alloy Co.
	Per cent.	*Per cent.*
Tungsten	70–80	70–80
Carbon, not over	.5	1
Manganese, not over		.5
Silicon, not over		1
Sulphur, not over	.05	.05
Phosphorus, not over	.08	.05
Copper		Trace.

The usual guarantee for carbon is now that the metal will contain less than 0.5 per cent. With an acid slag the percentage of carbon can be kept this low by a single operation, but with a basic slag the metal first produced must be refined. In smelting ferberite concentrate no difficulty is experienced in keeping the manganese in the ferrotungsten less than 0.5 per cent, but in smelting wolframite an acid slag must be used to cause the manganese to pass into the slag. Silicon seldom exceeds 1 per cent unless there is an excess of reducing agent in the charge. With a basic slag the sulphur usually runs less than 0.01 per cent, but with an acid slag it is easily kept below 0.05 per cent in the ferrotungsten. Phosphorus tends to be higher in the ferrotungsten produced by the single-stage acid process than in that made by the double-stage basic process, in which the phosphorus is removed as in the basic refining of steel. The percentage of copper in ferrotungsten is generally equal to that in the concentrate.

METHOD OF SAMPLING AND ANALYSIS OF FERROTUNGSTEN AND TUNGSTEN METAL POWDER.

The method of sampling and analyzing ferrotungsten and tungsten metal powder at the laboratories of the Tungsten Products Co., at Boulder, Colo., have been described especially for this bulletin by A. J. Guerber and F. J. Gibson, as follows:

PREPARATION OF SAMPLE.

The refined ferrotungsten, crushed and rolled to pass a ½-inch mesh screen, goes to a machine which automatically mixes, samples, and sacks the product for shipment. The sampler, which is of a special type developed by this company, cuts one-fifth of the total mix. This cut passes through the machine again after being rolled to approximately ¼-inch mesh. If the original mix is very large, the operations is repeated to bring the weight of the sample down to less than 500 pounds. This final sample from the automatic is passed repeatedly through a riffle sampler until the last cut weighs 15 to 50 pounds. This goes to the laboratory sampling department, where it is reduced in a steel mortar to pass a $\frac{3}{16}$-inch screen. The pounding necessary for this process is done by a 2-inch Ingersoll-Rand piston drill set up vertically in a frame above the mortar and pestle in such a manner that it is used as an air hammer, as shown by Plate XV, *A* (p. 43). The sample is thoroughly mixed and split twice, and one-quarter is then further reduced to pass a 10-mesh screen. This procedure of screening, mixing, and splitting is continued through a series of screens until the last portion passes the 200-mesh screen, giving the analyst about 100 grams of finely powdered metal. By this system the reduction of a 20-pound sample received from the smelter to a 100-gram laboratory pulp of 200-mesh powder requires about one hour.

DETERMINATION OF TUNGSTEN.

Mix two 1-gram samples separately in nickel crucibles with about 5 grams of sodium peroxide and a cover of sodium carbonate and fuse in an electric muffle at about 800° C.; it requires six to seven minutes to make a perfect decomposition. Cool, leach with water in covered 400-c. c. beakers. Remove crucibles and acidify carefully with hydrochloric acid, using moderate excess. Add about 2 c. c. nitric acid or H_2O_2, to assist in dissolving any small fragments of nickel oxide scale, and bring to a boil. Most of the tungsten separates as H_2WO_4 and all iron, nickel, and salts are in solution. Add about 40 c. c. cinchonine solution, stir and let stand in a warm place for about four hours, or preferably over night. This precipitates all the remaining tungsten as cinchonine tungstate, and has been proved as effective a reagent for this purpose as quinine hydrochloride.

Filter off the settled precipitate through a 15-cm. close-weave paper over a platinum cone and suction flask. Wash thoroughly with warm dilute cinchonine wash water, using gentle suction. The precipitate will not stick to the beaker if a few drops of hydrofluoric acid are used when copping out. The washed precipitate is transferred to a shallow gold dish of known weight and ignited to WO_3 in the muffle. Cool, moisten with 10 or 12 drops of hydrofluoric acid to remove any traces of SiO_2 which might be carried down, dry and ignite again. Weigh and calculate to W. The factor is 0.793. Duplicate determinations carried out in this way should check to within 0.10 per cent.

Cinchonine solution is prepared by dissolving 50 grams of cinchonine alkaloid in 2 liters of cold water containing 150 c. c. of hydrochloric acid.

Cinchonine wash water, made from 100 c. c. of the above cinchonine solution and 50 c. c. hydrochloric acid diluted to 1 liter with hot water and used from a bulb wash-bottle, is convenient.

DETERMINATION OF CARBON.

As ferrotungsten and tungsten metal powder burn completely and readily in oxygen, carbon is easily determined in any type of combustion train. In this laboratory the preferred method is to catch the CO_2 in a Meyer bulb in 2 per cent barium hydrate solution, filter, wash, and weight the $BaCO_3$.

DETERMINATION OF SULPHUR.

The usual fusion-oxidation methods of determining sulphur are open to objections when applied to a ferroalloy or other material whose sulphur content is below 0.05 per cent. The blank is always high, due to traces of sulphates in fluxes and reagents used and the danger of picking up fumes or traces of sulphuric acid from the apparatus of a general laboratory.

We have found that the sulphur content of ferrotungsten occurs as sulphides which, in a finely ground sample, are completely decomposed, yielding H_2S. This suggests at once the application of the evolution method, which has been used successfully in this laboratory for this purpose for two years.

Two to five grams of 200-mesh ferrotungsten or metal powder are weighted into an evolution flask. Cover with 50 c. c. water and add 25 c. c. strong hydrochloric acid by way of the separatory funnel. Heat to boiling and boil for about 10 minutes, catching the evolved gas, air, and steam in ammoniacal cadium chloride solution. The usual yellow precipitate of cadmium sulphide shows the presence of sulphides in the alloy. Wash the cadmium chloride solution from the bulbs, then cool, acidify with hydrochloric acid, and titrate at once against a weak iodine solution (1 c. c.=0.0005 g. sulphur), using starch as an indicator. The iodine solution is standardized by using a Government standard steel of known sulphur content, or by using a ferrotungsten of known sulphur content.

Boiling with dilute hydrochloric acid does not dissolve the alloy, but does decompose the sulphides present, as may be shown by filtering off the contents of the evolution flask after the operation and examining for sulphur by a fusion method or by a combustion method.

DETERMINATION OF PHOSPHORUS.

The removal of phosphorus from the alkaline liquor after a fusion decomposition of ferrotungsten presents certain difficulties. Precipitation with magnesia mixture from dilute solutions is incomplete unless much time is allowed for this step, also precipitation from concentrated solutions either as magnesium ammonium phosphate or as aluminium phosphate tends to drag down some tungsten, involving another step for its removal. To avoid these difficulties we have introduced the use of uranium acetate at this stage. The precipitation is quantitative from moderately dilute solutions and no dragging down of tungsten occurs. The details of procedure described in the following paragraphs are the result of considerable research and embody the experience of many hundreds of determinations made in this laboratory.

Weigh 1 gram sample into a nickel crucible containing 6 to 8 grams c. p. Na_2O_2. Mix thoroughly and cover with about 1 gram of c. p. Na_2CO_3. Ignite in a muffle to complete fusion of the fluxes. Cool and leach out carefully with warm water in a 250-c. c. covered beaker. Remove crucible and partly neutralize the NaOH with 25 c. c. HCl (1–3) to permit filtering without dilution. Stir and then allow the dense $Fe(OH)_3$ to settle out while standing on a warm plate.

Decant through a 12½-cm. qualitative paper into a 600-c. c. beaker. Wash precipitate into the filter, allow it to drain thoroughly, then give it two good washes with hot water, stirring up the precipitate well with a fine jet. Reserve this precipitate of $FE(OH)_3$, which contains a small amount of phosphorus, to add to the uranium precipitate obtained from the tungsten solution.

Acidify the filtrate of sodium tungstate and sodium phosphate with acetic acid, using 30 c. c. of 40 per cent acetic. Add 2 c. c. of 5 per cent uranium acetate solution. Boil off all CO_2. Make just alkaline with NH_4OH (1–1). This will require about 20 c. c. The precipitate is ammonium uranyl phosphate. Add 2 c. c. more uranium acetate, which precipitates at once as uranium hydroxide and serves to drag down the last traces of phosphate as well as to assist in filtering the ammonium uranyl phosphate. Boil off any large excess of NH_4OH. Filter through a qualitative paper and wash twice with hot water to remove tungsten. Place the precipitate in the same beaker with the iron precipitate obtained above, add 30 c. c. water and 25 c. c. strong nitric acid. Boil until both precipitates are in solution and the filters reduced to pulp. Filter into a 500-c. c. Erlenmeyer flask, washing the pulp once with hot water. Add 5 c. c. of 5 per cent $KMnO_4$ solution to acid filtrate. Boil to oxidize all phosphorus to H_3PO_4. Clear of MnO_2 by adding 2 c. c. H_2O_2 (1–1). Boil to remove excess H_2O_2 and cool under the tap. Add 45 c. c. NH_4OH (1–1), which will nearly neutralize the nitric acid, then 50 c. c. of molybdate solution. Stopper the flask and shake for five minutes, and let stand at least 15 minutes before filtering. Filter through a 9-cm. filter. Wash with acid ammonium sulphate, wash solution to remove all nitromolybdate.

Dissolve the yellow phosphomolybdate in hot dilute ammonia water, which must be free from chlorides, into the same Erlenmeyer flask. Wash the paper well with alternate washes of ammonia water and hot water. When cool, acidify with 5 c. c. of H_2SO_4 (1–1) and pass through the reductor, following with a thorough wash of cold water. Titrate against standard $KMnO_4$ solution to the same end point as used in determining the reductor blank.

The iron value of the standard permanganate solution times 0.0163 equals the P. value * * *. The ammonium sulphate wash solution must be distinctly acid. A good formula is:

H_2SO_4 (1–1), 100 c. c.; NH_4OH (1–1), 60 c. c.; water, 2 liters.

If convenient, it is well to allow the precipitate of yellow phosphomolybdate to stand about 1 hour after shaking for 2 minutes.

A blank on all reagents, including a fusion of Na_2O_2 and Na_2CO_3, should be carried through with the determinations. It is sometimes desirable to add a measured quantity of dilute phosphate solution of known P. content to the blank for close work.

Checks should agree within 0.015 per cent P.

The calculation of the P. factor is described by Lord and Demorest.[20] The composition of ammonium phosphomolybdate is expressed by the formula $(NH_4)_3PO_4.12MoO_3$, which shows that 1 P. is equivalent to 12 Mo, or 36 Fe.

Much has been written and many discussions have taken place in the past concerning the state of reduction of a molybdenum solution when passed through a Jones reductor. This controversy has been considered in detail in Randall's [21] article, and it has been proved conclusively that on passing through the reductor the molybdenum is reduced to Mo_2O_3 or $Mo_{12}O_{18}$.

The factor of 0.0163, described by Lord and Demorest, assumes that the MoO_3 solution is reduced to $Mo_{12}O_{19}$ rather than $Mo_{12}O_{18}$, as described by Randall. Therefore, in assuming the reduction as $Mo_{12}O_{19}$, one atom of P equals 34 atoms of Fe, whereas in using $Mo_{12}O_{18}$, one atom of P equals 36 atoms of Fe or 12 atoms of Mo, as previously described, thus making the factor 0.0154 in place of 0.0163. The difference, however, that would result from using the factor 0.0154 would be so small that it could, for ordinary analysis, be neglected. Assuming a normal permanganate solution, this difference would for 1 c. c. amount to 0.000058 gram P; for tenth or twentieth normal, which would be the strength most likely used, this figure would be correspondingly diminished.

This uncertainty as to the reduction factor, etc., can be overcome if the permanganate solution is standardized against a standard steel ore or pig iron, of known phosphorus content, which should be treated by the method used in the regular analysis.

BUYING OF TUNGSTEN ORES.

The buying specifications of tungsten ores have been summarized by Young,[22] as follows:

> It is unfortunate that the buying of tungsten ores in accordance with definite grades and specifications has not been standardized. Changing specifications and uncertainty respecting the marketability of tungsten ores and concentrates have made it difficult for some producers to satisfy themselves that they have received a fair price for their product. Prices are made on the basis of per unit of tungstic acid on the short ton. Scheelite and wolframite are recognized as

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[20] Lord, N. W., and Demorest, D. J., Metallurgical analysis, 4th ed., 1916, p. 50.

[21] Randall, D. L., The behavior of molybdic acid in the zinc reductor: Am. Jour. Sci., ser. 4, vol. 24, 1907, p. 313.

[22] Young, G. J., The tungsten industry in 1918: Eng. and Min. Jour., vol. 107, Jan. 11, 1919, p. 78.

two important types, although there is little distinction in price of either type where the accompanying impurities do not exceed the following amounts: Sulphur, not over 0.1 per cent; copper, not over 0.02 per cent; tin, not over 0.02 per cent; phosphorus, not over 0.02 per cent. Ores of this type are termed pure or high-grade ores, and where they exceed 60 to 65 per cent WO_3 or over they command the highest prices. The scheelite concentrate and ore of the Atolia mine are in a separate class and also command a high price. All other ores, whether scheelite, wolframite, or otherwise, are classed as impure ores, and are sold at various prices, depending on the amount and kind of impurity as well as upon the facilities of the buyer for the treatment of the different kinds of ore.

That the limits given are not universally recognized is shown by Charles Hardy's classification, which places the maximum percentage of impurity for high-grade ore and concentrate at: Tin 0.05 per cent; copper, 0.05 per cent; and phosphorus, 0.04 per cent. All ores and concentrates exceeding these amounts of impurity are called off-grade ores. Other firms have specifications which make no use of the terms high-grade, off-grade, or impure, but merely specify the lower limit of tungstic acid and the upper limit of certain impurities. The highest-grade wolframite marketed contains 70 per cent tungstic acid, traces of tin and copper, and manganese under 1 per cent. Tungstic acid content ranges from 10 to 72 per cent, although there is recognized, to some extent at least, a base grade containing 65 per cent tungstic acid. In some cases a 60 per cent grade is named. There is no recognized deduction or addition in price for a variation in tungstic acid content in either direction from the base grade. Ores with impurities may contain the followng range: Sulphur, up to 3 or 4 per cent; tin, up to 10 per cent; copper, up to 3 per cent; phosphorus, up to 0.3 per cent. Certain foreign ores even exceed these percentages, as the tungstic acid content may reach 45 per cent; copper, 6 per cent; and tin, 19 per cent. Some buyers handle only scheelite, others wolframite, and still others both types. There is need for a clean-cut classification.

Hess,[23] in summing up the quality of ore demanded by users, says:

> Most of the processes used for reducing tungsten from its ores also partly or wholly reduce nearly all the metallic and some other impurities in the ores, and these impurities are carried with the tungsten into the steel to which it is added. For such use iron makes no difference, but a number of other elements are not wanted, either because, like copper and phosphorus, they are detrimental to the steel or because, like manganese, if they are wished in the steel they can be added more advantageously in some other way. Objectionable impurities found in tungsten ores are antimony, arsenic, bismuth, copper, lead, manganese, nickel, tin, zinc, phosphorus, and sulphur. Few of these occur in large quantity in ores found in this country. Copper is perhaps the commonest hurtful impurity, and therefore most is said about it, but ores from some foreign countries contain nearly all the impurities mentioned. During the early part of 1916 tungsten ores were so eagerly sought that nearly all offered were bought with little objection to impurities, but under more normal conditions consumers are much more particular.
>
> The wet chemical processes give more opportunity to get rid of most impurities than the electrolytic process, so that companies using wet chemical processes are, as a rule, though not uniformly, least particular about the ores they buy. Two of the firms that use wet chemical processes buy tungsten ores

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[23] Hess, F. L., Tungsten minerals and deposits: U. S. Geol. Survey Bull. 652, 1917, p. 74.

almost without regard to the impurities present, but one objects to more than 2 per cent copper, and both buy ores containing as little as 20 per cent WO_3.

Only the one firm mentioned is known that does not object to copper in any grade of ore. Another will take cupriferous ore if the content of WO_3 is sufficiently high. The others either will not take copper-bearing ore when other ores are to be obtained or set limits of 0.2 to 2 per cent copper and not less than 50 per cent WO_3, except that one firm will take ores that carry 5 per cent or more copper, for such a percentage will pay for separation.

Two companies take ores without regard to impurities other than copper, provided the content of WO_3 is sufficiently high. Most of the companies object to tin, sulphur, phosphorus, antimony, arsenic, bismuth, lead, and zinc; two of them object to manganese; and one to nickel. The last company referred to set extreme limits of 0.25 per cent for phosphorus, 0.25 per cent for nickel, 6 per cent for manganese, and a trace of arsenic.

ORE SCHEDULE.

A typical ore-schedule sheet follows:

TABLE 8.—*A typical ore-schedule sheet.*

[Schedule of prices for tungsten ore delivered at mill. Subject to change without notice. No sampling and assaying on lots over $50 in value. In effect with tungsten at about $18 per unit, f. o. b. New York.]

	Per pound.	Per ton.		Per pound.	Per ton.
Tungstic acid:	*Cents.*		Tungstic acid—Continued.	*Cents.*	
2 per cent	12	$4.80	32 per cent	47.4	$303.60
3 per cent	15	9.00	33 per cent	47.4	313.40
4 per cent	22	17.60	34 per cent	47.5	323.30
5 per cent	31	31.00	35 per cent	47.6	333.00
6 per cent	36	43.20	36 per cent	47.6	342.80
7 per cent	40	56.00	37 per cent	47.6	352.60
8 per cent	42	67.20	38 per cent	47.6	362.40
9 per cent	43	77.40	39 per cent	47.7	372.20
10 per cent	43.5	87.00	40 per cent	47.7	382.00
11 per cent	44	96.80	41 per cent	51.2	420.25
12 per cent	44.7	107.40	42 per cent	52.5	441.00
13 per cent	45.2	117.60	43 per cent	53.7	462.25
14 per cent	45.4	127.20	44 per cent	55	484.00
15 per cent	45.6	137.00	45 per cent	56.1	506.25
16 per cent	45.6	146.00	46 per cent	57.5	529.00
17 per cent	46	156.60	47 per cent	58.7	552.25
18 per cent	46.2	166.40	48 per cent	60	576.00
19 per cent	46.3	176.20	49 per cent	61.2	600.25
20 per cent	46.5	186.00	50 per cent	62.5	625.00
21 per cent	46.6	195.80	51 per cent	63.7	650.00
22 per cent	46.7	205.60	52 per cent	65	676.00
23 per cent	46.8	215.40	53 per cent	66.5	702.25
24 per cent	46.9	225.20	54 per cent	67.5	729.00
25 per cent	47	235.00	55 per cent	67.5	756.00
26 per cent	47	244.80	56 per cent	70	784.00
27 per cent	47.1	254.60	57 per cent	71.6	812.25
28 per cent	47.2	264.40	58 per cent	72.4	841.00
29 per cent	47.2	274.20	59 per cent	73.7	870.00
30 per cent	47.3	284.00	60 per cent	75	900.00
31 per cent	47.4	293.80			

PRODUCTION OF TUNGSTEN CONCENTRATES IN THE BOULDER DISTRICT, IN THE UNITED STATES, AND IN THE WORLD.

The production of tungsten concentrates in Colorado has been, as shown in Table 9 below, taken from the Fifteenth Biennial Report of the Colorado Bureau of Mines, 1917–18, page 121:

TABLE 9.—*Tungsten production of Colorado.*

	Tons.	Price per unit.	Total value.
1900. High-grade ore, 63 per cent WO_3	40	$1.30	$3,216
1901. High-grade ore and concentrates averaging 65 per cent WO_3	65	2.25	8,875
1902. Ores and concentrates	166	2.50	24,900
1903. Mainly concentrates	243	2.50	36,317
1904. Ores and concentrates averaging 55 per cent WO_3	375	5.50	125,000
1905. Mainly concentrates	642	6.00	231,120
1906. Mainly concentrates	789	6.54	309,603
1907. Mainly concentrates	1,146	8.83	573,643
1908. High-grade ore 180	587		164,220
Concentrates 407			
1909. Production on basis of 60 per cent WO_3	993	$5.00- 9.00	391,160
1910. Production on basis of 60 per cent WO_3	1,221	6.50- 8.50	553,100
1911. Production on basis of 60 per cent WO_3	730	4.50- 8.50	261,492
1912. Production on basis of 60 per cent WO_3	775	5.60- 7.50	293,611
1913. Production on basis of 60 per cent WO_3	953	7.50	428,726
1914. Production on basis of 60 per cent WO_3	630	5.85- 9.00	252,000
1915. Production on basis of 60 per cent WO_3	960	5.50-45.00	1,688,640
1916. Production on basis of 60 per cent WO_3	2,401	34.15	4,919,649
1917. Production on basis of 60 per cent WO_3	2,707	20.00	3,248,400
1918. Production on basis of 60 per cent WO_3	1,910	16.00	1,833,600

Nearly all of Colorado's production was from the Boulder district. It was in 1898 that wolfram ores were first reported found at various places in Colorado, but no shipments were made.[24] The first shipment reported from Colorado was in 1899, when Poulot and Voilleque mined 3 tons of ore; the location, however, was not given.[25]

In the following discussion concerning production, all calculations are based on short tons containing 60 per cent WO_3 unless otherwise stated. Statistics and questions concerning the quantities produced in the United States by districts and States, world production by countries, imports and exports, uses, prices, mining conditions, etc., of tungsten are found in "Mineral Resources of the United States," published annually by the United States Geological Survey; also in "The Mineral Industry," published annually by the McGraw-Hill Co., of New York. Besides these two principal sources of information, reports from the State bureaus of mines or mining bureaus and the current technical journals furnish data.

In 1900 the first important shipments of tungsten concentrates were made, and since then Colorado has ranked as the chief producing State.

BOULDER COUNTY PRODUCTION FOR PERIOD 1914–1919, AS COMPARED TO THAT OF CALIFORNIA.

According to Mineral Resources for 1914, the production of the Atolia field in the Mojave Desert, Calif., for that year exceeded that of Boulder County, Colo., for the first time. It was claimed that Boulder County produced 467 tons out of the country's total production of 990 tons. The table as given above for Colorado's production represents 630 tons produced in Colorado for 1914, which practically all came from the Boulder field.

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[24] The Mineral Industry, 1898, vol. 7, p. 719.

[25] The Mineral Industry, 1899, vol. 8, p. 632.

In 1915 Colorado's production, 963 tons, was practically equal to the production of California, 962 tons; also, according to Hess, the total production of the United States for 1915 was 2,332 tons.[26]

The production of tungsten ores in the United States for 1916 was the largest ever made by any country in the world, the amount being 5,923 tons, valued at $12,074,000; Colorado again exceeded California, producing 2,401 tons against California's 2,171 tons.[27]

As Mineral Resources for 1917 was not available when this report was written, the data for 1917 has been taken from the Mineral Industry, 1917, vol. 26, p. 699. California is given as the largest tungsten-producing State; in fact, as the largest scheelite producer of the world. Production for 1917 is given as 2,250 tons against 2,200 tons for Colorado. The United States produced 5,313 short tons. According to the tungsten production table of Colorado, as given above, Colorado produced in 1917, 2,707 tons; and, according to the report of the California State Mining Bureau, 2,458 tons were produced in California.[28]

The production of tungsten ores in the United States for 1918, as given by Hess,[29] was less than that of the preceding two years, and was 5,065 short tons of concentrates, carrying 60 per cent tungsten trioxide. The largest producing State was Colorado, with 1,910 tons of ferberite. California produced 1,781 tons of scheelite, and Nevada 885 tons of scheelite. According to the California State Mining Bureau, under date of August 13, 1919, the production of concentrates in 1918 was 1,982 tons.

The production for 1919 for the Boulder district can be but roughly estimated, for during the early part of the year, after the price of tungsten dropped to around $13 a unit, practically all the mills closed, and some went completely out of business. The two largest producers, the Wolf Tongue and the Primos, closed their mills completely about March. The probable production for 1919 has been placed at 500 tons of concentrates. Production in August, 1919, was practically at a complete standstill, as tungsten concentrates (60 per cent WO_3) were selling at $7 to $10 a unit. The only mill found in operation during a brief visit by the writers in August, 1919, was the Vasco at Tungsten, Colo., which was producing about 20 tons of tungsten concentrates per month. The Red Sign mill at Ferberite had been completely dismantled and the equipment moved out of the district.

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[26] Hess, F. L., Tungsten: Mineral Resources of the United States, 1915, p. 823.

[27] Hess, F. L., Tungsten: Mineral Resources of the United States, 1916, p. 789.

[28] Tungsten, molybdenum, and vanadium, Report No. 4, March, 1918, p. 9.

[29] Hess, F. L., Tungsten ore production in 1918: Eng. and Min. Jour., vol. 107, Feb. 8, 1919, p. 285.

The two largest producing mines of California—the Atolia and the Tungsten Mines Co.—closed down in March, 1919, and September, 1919, respectively. The mines in the Nevada field closed down after operating only a few months.

The summary of the tungsten market situation in 1919 [30] and the tungsten mining industry in 1919 [31] has been given in the annual review number of the Engineering and Mining Journal.

Little tungsten ore was produced in the United States in 1919, and a vast stock accumulated principally from the Far East that sold for around $7 a unit, which caused the American mines to close.

Figures, as given in the Mineral Resources, give production for California and Colorado in 1919 at 277 short tons of 60 per cent WO_3 concentrates valued at $323,799.

PRODUCTION OF TUNGSTEN ORES IN THE UNITED STATES.

The production of tungsten ores in the United States has been, as shown in Table 10, taken from Mineral Resources.[32]

Production has been recorded by Mineral Resources, United States Geological Survey, only since 1900. Before that time it was insignificant. In 1897 there was no production of tungsten ores in the United States; the demands did not exceed 70 to 80 tons per annum.[33] The amounts produced in 1898 and 1899 were negligible.

TABLE 10.—*Concentrated tungsten ores produced in the United States, 1900–1919.*

Year.	Quantity (short tons).	Value.	Year.	Quantity (short tons).	Value.
1900	46	$11,040	1910	1,821	$832,992
1901	179	27,720	1911	1,139	407,985
1902	184	34,040	1912	1,330	502,158
1903	292	43,639	1913	1,537	672,118
1904	740	184,000	1914	990	435,000
1905	803	268,676	1915	2,332	4,100,000
1906	928	348,867	1916	5,923	12,074,000
1907	1,640	890,048	1917	6,144	6,783,000
1908	671	229,955	1918	5,061	7,049,300
1909	1,619	614,370	1919	327	353,900

The production of tungsten ores in this country from year to year can be fairly compared in the table only since and beginning with

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[30] Hardy, Charles, The tungsten market situation in 1919: Eng. and Min. Jour., vol. 109, No. 3, Jan. 17, 1920, p. 210.

[31] Young, George J., The tungsten mining industry in 1919: Eng. and Min. Jour., vol. 109, No. 3, Jan. 17, 1920, p. 211.

[32] Hess, F. L., Tungsten: Mineral Resources of the United States, 1916, p. 789.

[33] Mineral Industry, 1897, vol. 6, p. 651.

1906, as before that date no effort was made to reduce the ores to a common basis of tungsten content. Since 1906 the ores have been, as far as possible, reduced to an equivalent of ore carrying 60 per cent of tungsten trioxide (WO_3), which is the ordinary commercial basis in the United States.

According to Frank L. Hess,[34] not since 1902 has the United States produced so small a quantity of tungsten concentrates as in 1920. The Wolf Tongue Mining Co. and the Vasco Mining Co., of Boulder, Colo., were the only American tungsten mines. They produced an equivalent of 216 short tons of ferberite ore carrying 60 per cent tungsten trioxide (WO_3). The large stock of tungsten ores on hand carried over from 1919, and the continued importation of tungsten ores from China and South America, coupled with the low price a unit, between $7 and $3 for 60 per cent grade, kept the American producing mines closed. The prices for 1920 and continuing in 1921, at $3 a unit, have never been so low in the entire history of the tungsten industry, except previous to 1904, as shown in Table 10.

COST OF PRODUCTION IN BOULDER COUNTY DISTRICT.

Before the war the average cost of production for the Boulder district had been conservatively placed at $11 to $12 a unit. In some of the small mills treating low-grade ore the cost had exceeded these figures. In April, 1916, tungsten ore sold at $75 to $85 a unit in New York. In May, 1916, the price dropped to a nominal quotation of $40 a unit. In September, 1916, tungsten ore could be freely purchased for about $17 a unit. During the fall of 1916—when tungsten was selling for that price—several of the smaller tungsten mills in the district closed down, and it was stated then that the marginal profits were too small and would not warrant continuing operations. The largest producers, however, continued work, for, beginning with the summer of 1917 and to the signing of the armistice in November, 1918, the market for tungsten ore remained practically steady, around $20 a unit, enough to warrant a fair margin of profit.

Mining conditions have considerably changed from what they were in 1916 and 1917. Then the ore as soon as it was discovered, was gutted out; practically all the easily accessible ore in sight was quickly mined and very little systematic development was done. Now, the situation at the mines is different; with no easily accessible ore in sight, considerable new development and opening of new ore bodies must be done, and consequently this, coupled with the increased salaries demanded by the miners, has greatly raised the cost of production.

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[34] Hess, F. L., Tungsten in 1920: Chem. and Met. Eng., vol. 24, No. 17, Apr. 27, 1921, p. 757.

When tungsten dropped to around $13 a unit in the spring of 1919, practically all the mills closed; some went completely out of business and moved their equipment out of the district. In August, 1919, only one mill was in operation—the Vasco mill at Tungsten, Colo. This mill was working on high-grade ore one shift a day, employing four men. The company claimed it was running simply to maintain the mill in good condition.

From the facts given above, and from the opinion of the tungsten producers of the district, it can be safely said that the average cost of production under conditions existing when this report was written is about $17 per unit.

WORLD'S PRODUCTION OF TUNGSTEN ORE.

Table 11 summarizes the total production of tungsten ore, 1905 to 1916, according to Hess.[35] For the detailed productions in the different countries the reader is referred to Mineral Resources or Mineral Industry.

TABLE 11.—*World's production of tungsten ore.*

[Estimated as far as possible in short tons of concentrate containing 60 per cent tungsten trioxide.]

Date.	Tons.
1905[a]	4,026
1906[a]	4,367
1907	6,137
1908	4.118
1909	5.774
1910	7,570
1911	7,517
1912	9,710
1913	8,864
1914	7,813
1915	11,840
1916	23.360
1917	25,523
1918	31,865
1919	12,000

[a] Mineral Resources for 1914, p. 938.

During the period shown the United States was the chief producer, excepting in 1912, 1913, 1914, and 1915, when Burma and the Shan States were the chief producers.

CHINA AS A PRODUCER OF TUNGSTEN ORE.

As regards tungsten production in China,[36] Hess[37] has said:

> The present largest producer outside of the United States is China. Tungsten ores were found in China in 1917—that is, the first production that amounted

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[35] Mineral Resources for 1916, p. 797.

[36] Kappel, H., Chinese tungsten and the American market: Eng. and Min. Jour., vol. 111, No. 7, 1921, p. 308.

[37] Hess, F. L., Tungsten production analyzed: Jour. Am. Min. Congress, July, 1919, p. 231.

to anything. They produced about 1,500 tons of ore. In 1918 they shipped something like 10,500 tons. The ore is found as placer stuff, where the veins have worn down so the material in the veins has been washed away, leaving this wolframite in the dirt and stream beds. There is going to be a lot of ore coming from China because they have gotten down to mining the veins.

BOLIVIA AND PORTUGAL AS PRODUCERS.

Bolivia produced in 1916, 3,624 tons, and, according to Hess,[38] is perhaps the third largest producer at the present time. Portugal is the largest producer in Europe.

UNITED STATES IMPORTS, EXPORTS, AND CONSUMPTION.

IMPORTS OF TUNGSTEN ORE, TUNGSTEN METAL, AND FERROTUNGSTEN.

Table 12 represents only in a brief form the value of the imports of tungsten ores, tungsten, and ferrotungsten in this country from 1902 to 1916; for detailed figures assigned to countries, etc., the reader is referred to the original tables given under the section "Tungsten" in Mineral Resources, or to figures compiled by the Division of Statistics of the Bureau of Foreign and Domestic Commerce.

Prior to 1908 the tungsten imports of ore into this country were in the form of ferrotungsten and tungsten metal or powder. No data has been given for the figures not given below.

TABLE 12.—*Imports of tungsten ore, tungsten metal, and ferrotungsten.*

Year.	Tons of ore (short tons).	Value.	Tons of tungsten and ferrotungsten (long tons).	Value.
1902	(a)	(a)	(a)	$7,046
1903	(a)	(a)	(a)	18,136
1904	(a)	(a)	(a)	29,439
1905	(a)	(a)	(a)	13,525
1906	(a)	(a)	(a)	....
1907	(a)	(a)	(a)	39,417
1908	(a)	(a)	(a)	488
1909	(a)	$105,506	(a)	93,205
1910	852	344,979	528.0	678,534
1911	294.5	368,618	115.07	143,802
1912	824	362,422	288	323,872
1913	401	213,122	661	835,212
1914	299	139,687	195	222,447
1915	1,534	1,044,986	7.0	9,588
1916	4,071	7,353,691	38.0	157,711
1917	4,880	4,467,608	1.0	3,606
1918[d]	[b]10,362	11,409,237	(c)	....
1919[d]	8,400	6,261,190	....	....

[a] Not given.

[b] First six months ended June 30, 1918. Total imports for 10 months ended Oct. 31, 1918, were 7,001 tons, valued at $7,536,875, as against 4,373 tons, valued at $3,594,961, for the corresponding period of 1917, according to the Department of Commerce.

[c] 396,460 pounds.

[d] From Mineral Industry, vol. 28, 1919. p. 689.

[38] Hess, F. L., Work cited, p. 231.

The imports for 1920, according to Hess,[39] were equivalent to about 2,111 short tons of concentrates carrying 60 per cent WO_3. Besides the ore, 1,997,719 pounds of tungsten and ferrotungsten were imported, equivalent to about 2,250 short tons of 60 per cent ore. Hess estimates that probably more than a three years' supply is on hand, based on the average consumption before the World War.

EXPORTS.

Before the war very little was exported; so little, in fact, that the Government published no separate report. A few published figures concerning exports are as follows:

The exports of tungsten metal and alloy amounted to 2,323,811 pounds, valued at $4,122,653, in 1917, compared with 574,321 pounds, valued at $1,352,631, in 1916.[40] Exports for 1919 totaled 38,130 pounds, valued at $113,276, as compared with 1,232,260 pounds, valued at $2,545,087, in 1918.

The submarine *Deutschland*, on her second trip in December, 1916, carried back to Germany 55,125 pounds of tungsten and ferrotungsten, valued at $137,812.[41]

CONSUMPTION OF TUNGSTEN DURING 1918.

The largest consumption of tungsten in the United States was during the year 1918, as recorded by the Bureau of Mines. The following excerpt from Reports of Mineral Investigations of the United States Bureau of Mines, June, 1919, gives in detail the amount of tungsten consumed.[42]

> *Ten million pounds of tungsten used in 1918.*—An interesting summary of the consumption of tungsten in 1918, based on questionnaires distributed by the Bureau of Mines, shows that the tungsten used in the making of tungsten powder, ferro, and acid, from May to December, 1918, amounted to about 7,500,000 pounds, from which it is estimated that the total tungsten used in such products for the calendar year of 1918 was nearly 10,000,000 pounds, and that the amount of tungsten used in making malleable products during the same time was approximately 210,000 pounds. The quantity of high-speed steel made from May to December, 1918, was nearly 30,000,000 pounds, from which it is estimated that the total weight of such steel in the year was somewhat in excess of 40,000,000 pounds; the tungsten content was properly nearly 7,000,000 pounds. The tungsten steel made from May to December, 1918, was in excess of 45,500,000 pounds, from which it is estimated that the total quantity produced in 1918 was approximately 62,000,000 pounds. The amount of 60 per cent

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[39] Hess, F. L., Tungsten in 1920: Chem. and Met. Eng., vol. 24, No. 17, Apr. 27, 1921, p. 757.

[40] Fink, C. G., Mineral Industry for 1916, vol. 25, 1917, p. 722; for 1917, vol. 26, 1918, p. 699; for 1919 and 1918, vol. 28, 1920, p. 689.

[41] Hess, F. L., Nickel: Mineral Resources, 1916, U. S. Geol. Survey, 1919, p. 783.

[42] Mining Cong. Jour., vol. 5, August, 1919, p. 270; Chem. and Met. Eng., vol. 21, Aug. 15, 1919, p. 200.

concentrates required to make the tungsten powder, ferro, and acid used in 1918 was approximately 13,000 tons, assuming that 1 ton of 60 per cent concentrates is reduced to 760 pounds of contained tungsten in ferro.

The total consumption of tungsten concentrates in the United States in 1919 amounted to approximately 7,500 short tons. Consumption for 1920 is estimated at about 4,500 tons.[43]

The following diagram (Pl. XVIII) of tungsten products shows how tungsten is utilized:

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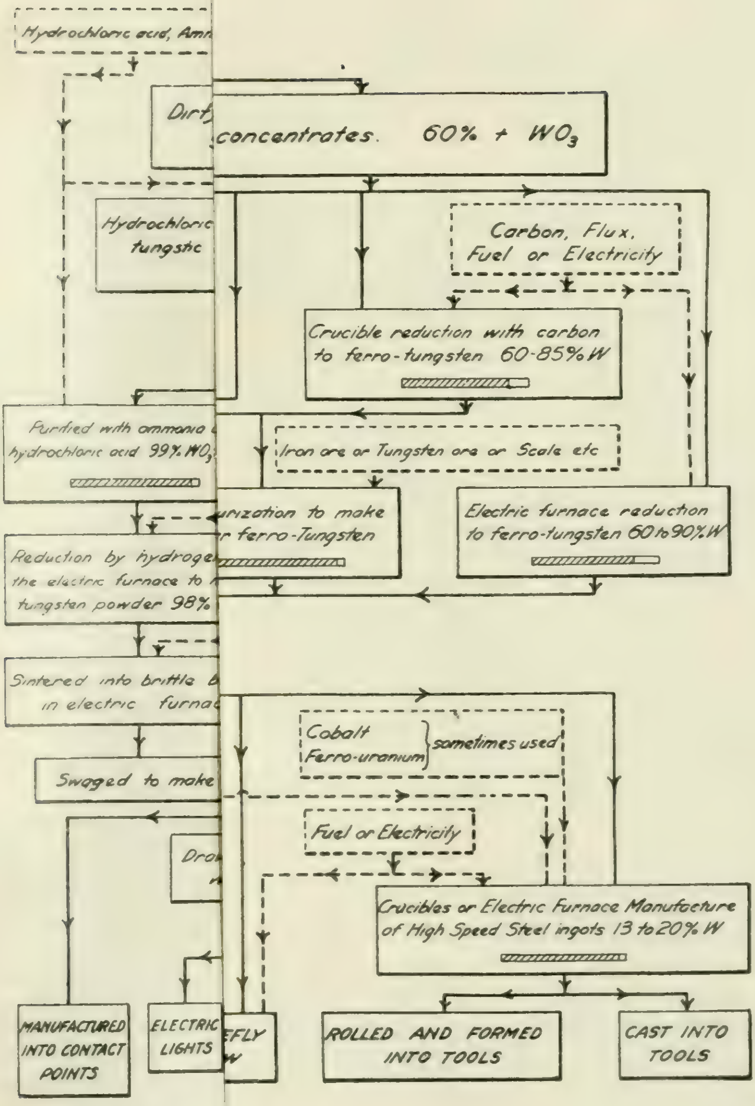
[43] Mineral Industry, vol. 28, 1919, p. 689.


Hydrochloric acid, Amn
Dirt
concentrates. 60% + WO_3
Hydrochloric
tungstic
Carbon, Flux, Fuel or Electricity
Crucible reduction with carbon to ferro-tungsten 60-85% W
Purified with ammonia
hydrochloric acid 99% WO_3
Iron ore or Tungsten ore or Scale etc
urization to make
r ferro-Tungsten
Electric furnace reduction to ferro-tungsten 60 to 90% W
Reduction by hydroge
the electric furnace to
tungsten powder 98%
Sintered into brittle b
in electric furna
Cobalt
Ferro-uranium
sometimes used
Swaged to make
Fuel or Electricity
Dra
Crucibles or Electric Furnace Manufacture of High Speed Steel ingots 13 to 20% W
MANUFACTURED INTO CONTACT POINTS
ELECTRIC LIGHTS
EFLY
W
ROLLED AND FORMED INTO TOOLS
CAST INTO TOOLS

30537—21. (To fac

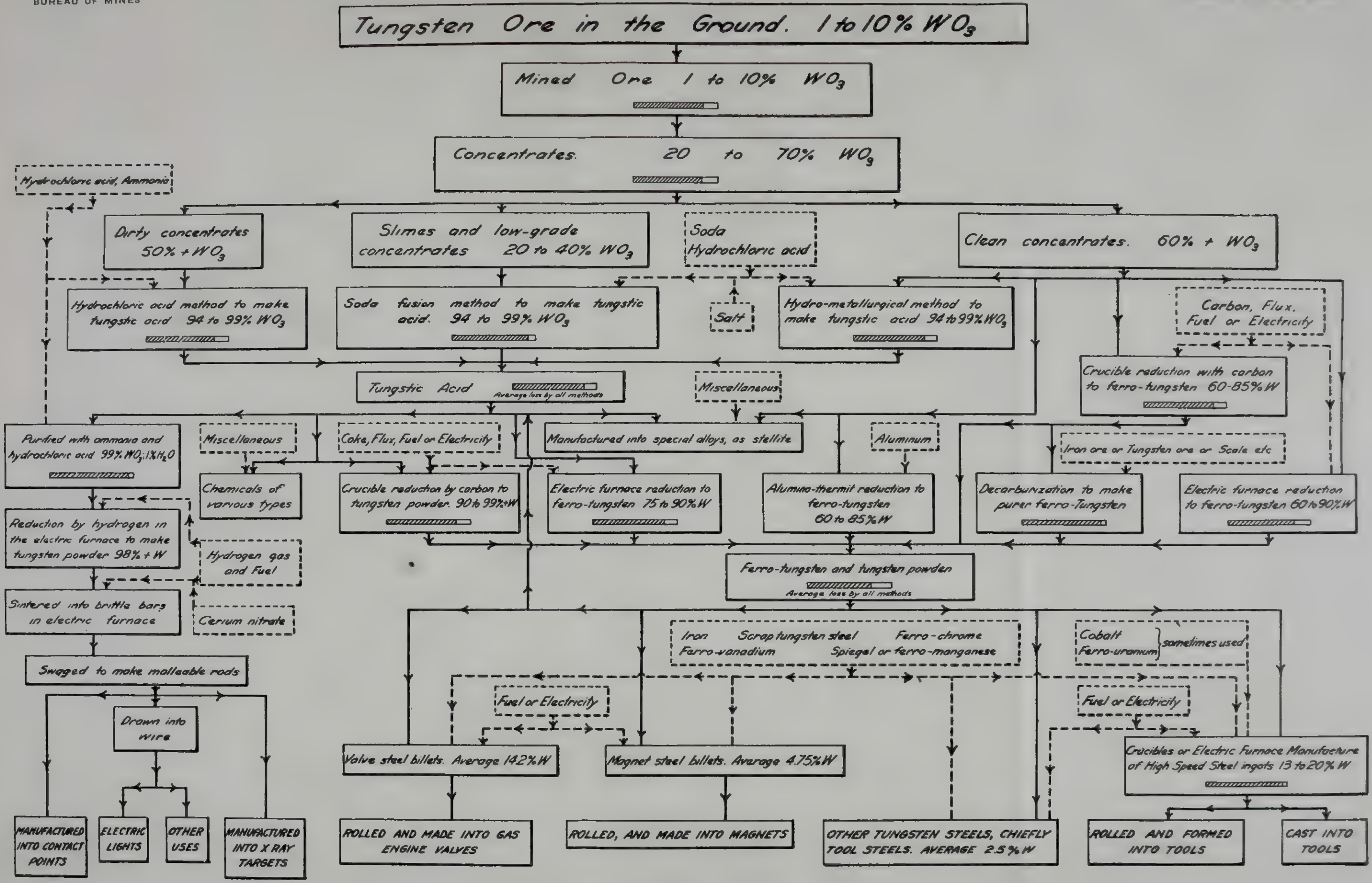

Tungsten Ore in the Ground. 1 to 10% WO_3
Mined Ore 1 to 10% WO_3
Concentrates. 20 to 70% WO_3
Hydrochloric acid, Ammonia
Dirty concentrates 50% + WO_3
Slimes and low-grade concentrates 20 to 40% WO_3
Soda Hydrochloric acid
Clean concentrates. 60% + WO_3
Hydrochloric acid method to make tungstic acid 94 to 99% WO_3
Soda fusion method to make tungstic acid. 94 to 99% WO_3
Salt
Hydro-metallurgical method to make tungstic acid 94 to 99% WO_3
Carbon, Flux, Fuel or Electricity
Tungstic Acid
Average loss by all methods
Miscellaneous
Crucible reduction with carbon to ferro-tungsten 60-85% W
Purified with ammonia and hydrochloric acid 99% WO_3, 1% H_2O
Miscellaneous
Coke, Flux, Fuel or Electricity
Manufactured into special alloys, as stellite
Aluminum
Iron ore or Tungsten ore or Scale etc
Chemicals of various types
Crucible reduction by carbon to tungsten powder. 90 to 99% + W
Electric furnace reduction to ferro-tungsten 75 to 90% W
Alumino-thermit reduction to ferro-tungsten 60 to 85% W
Decarburization to make purer ferro-Tungsten
Electric furnace reduction to ferro-tungsten 60 to 90% W
Reduction by hydrogen in the electric furnace to make tungsten powder 98% + W
Hydrogen gas and Fuel
Ferro-tungsten and tungsten powder
Average loss by all methods
Sintered into brittle bars in electric furnace
Cerium nitrate
Iron Scrap tungsten steel Ferro-chrome Ferro-vanadium Spiegel or ferro-manganese
Cobalt Ferro-uranium sometimes used
Swaged to make malleable rods
Fuel or Electricity
Fuel or Electricity
Drawn into wire
Valve steel billets. Average 14.2% W
Magnet steel billets. Average 4.75% W
Crucibles or Electric Furnace Manufacture of High Speed Steel ingots 13 to 20% W
MANUFACTURED INTO CONTACT POINTS
ELECTRIC LIGHTS
OTHER USES
MANUFACTURED INTO X RAY TARGETS
ROLLED AND MADE INTO GAS ENGINE VALVES
ROLLED, AND MADE INTO MAGNETS
OTHER TUNGSTEN STEELS, CHIEFLY TOOL STEELS. AVERAGE 2.5% W
ROLLED AND FORMED INTO TOOLS
CAST INTO TOOLS

DIAGRAM OF TUNGSTEN PRODUCTS

EXPLANATION

Broken lines indicates materials containing no Tungston used in making Tungsten products

The shaded portion of the bar indicates the approximate average recovery in the operation making that product

The percentages show the Tungsten content of each product

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